



National Aeronautics and Space Administration

# **Nuclear Compton Telescope Balloon Launch in Alice Springs, Northern Territory, Australia High Visibility Type B Mishap IRIS Case Number S–2010–119–00007 Volume I of II**



**Date of Mishap: April 29, 2010**

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## **Foreword**

The Nuclear Compton Telescope Balloon Launch Mishap Investigation Board (MIB) was commissioned on May 12, 2010 to gather information, analyze facts, and identify the proximate cause(s), intermediate cause(s), and root cause(s) that resulted in the mishap. The MIB was also instructed to identify any observations and contributing factors related to the mishap. Finally, the MIB was asked to generate recommendations that could be implemented within NASA to prevent similar mishaps and to correct organizational issues that may lead to additional mishaps occurring in the future. The MIB's intent and purpose were not to place blame or to determine legal liability for the mishap, but only to act as an Independent Investigation Authority according to the guidelines in NASA Procedural Requirement (NPR) 8621.1B.



## Executive Summary

### General Information

On April 29, 2010, at 08:08 a.m. Australian Central Time (ACT), a NASA High Visibility, Type B Mishap occurred at the Alice Springs International Airport in Alice Springs, Northern Territory (NT), Australia. The incident was given the Incident Reporting Information System (IRIS) case number: S-2010-119-0007.

Personnel from the Columbia Scientific Balloon Facility (CSBF), a NASA contractor, were attempting to launch the Nuclear Compton Telescope (NCT) scientific balloon payload using a conventional balloon. NCT was a balloon-borne gamma-ray telescope designed to study astrophysical sources of nuclear line emission with high spectral and spatial resolution. The launch team reported to duty around 2 a.m. on April 29, 2010, ACT. Weather conditions were deemed favorable for a launch attempt, so the launch team assembled the balloon and payload hardware at the launch site. All pre-launch preparations were nominal and after the balloon bubble was inflated with helium, the Launch Director (LD) was given authority to launch by the Site Director (SD) who was communicating with Melbourne Air Traffic Control. After the balloon bubble was released from the spool, it took flight and lifted the flight train. While initially maneuvering the launch vehicle for the launch attempt, the balloon slightly overtook the launch vehicle's position. The LD instructed the driver to make a left turn in order to make up ground on the balloon. Approximately 76 seconds after initiating motion of the launch vehicle, the LD slowed the vehicle for a launch attempt. During the launch attempt, in which the LD pulls on a release lanyard, the payload failed to release from the launch vehicle. Subsequently, the launch vehicle was accelerated in an attempt to catch up with the balloon for a second release effort. Upon reaching the airport fence the CSBF team recognized that the mission would have to be terminated and the LD attempted to maneuver the launch vehicle to a safe position after observing that spectators were in harm's way. In the process of maneuvering the crane, the payload inadvertently broke free of the launch vehicle and was dragged by the wind-driven balloon through the airport fence and into an unoccupied vehicle that was owned by a public spectator. The spectator, who was photographing the launch attempt, was able to jump off the roof of his vehicle just prior to the collision. Other spectators were observed scrambling to avoid the payload. While no injuries occurred, the payload and the privately-owned vehicle suffered extensive damage and as stated, several spectators were nearly struck by the payload. Subsequently, videos produced by the Australian Broadcasting Company of the launch attempt were aired on numerous international news programs and were immediately available on the Internet.

A Mishap Investigation Board (MIB) was appointed on May 12, 2010 to perform an investigation of the incident. The incident was initially deemed a High Visibility Close Call mishap and was later reclassified as a High Visibility, Type B mishap (breakdown of cost estimates are in Appendix I).

Based on mishap site visits to Alice Springs, NT, Australia, witness interviews, analyses and assessments, structural testing, and use of the Root Cause Analysis (RCA) Tool, the MIB identified the underlying causes of the mishap. An Event and Causal Factor Tree (E&CFT) diagram (Appendix A

and Section 3.6) was developed, resulting in the identification of the root causes (events or conditions that are organizational factors), proximate causes (events that occurred, including any conditions that existed immediately before the undesired outcome), and intermediate causes (events or conditions that created the proximate cause that, if eliminated or modified, would have prevented the proximate cause from occurring).

In summary, the causes for this mishap evolved from: (1) a flawed underlying assumption, (2) a problematic historical mindset, and (3) an ineffective organizational structure. First, the Balloon Program has been operating under an underlying assumption that the risks to the public only exist in the over flight of populated areas. This assumption has led to a very limited view of the hazards and their associated targets involved in launching balloons. Next, the decades of successful balloon launches under a tight budget have led to complacency and a sense that performance of safety and technical measures can be relaxed under the guise of risk acceptance. This mindset flows throughout WFF and apparently through the NASA Headquarters OSMA and SMD organizations. This mindset justified a further distinction between the safety practices in the balloon program and the safety practices of other programs at WFF. Lastly, there is an organizational structure at GSFC that bypasses the independent safety and mission assurance infrastructure that was set up at GSFC as it pertains to the Wallops Flight Facility (WFF). Hence GSFC's independent safety infrastructure does not provide an appropriate control for unsafe practices within the balloon program or an independent safety assurance organization with line authority over all levels of safety oversight.

All voting members of the board participated in the investigation, deliberations, and development of the findings and recommendations. Upon completion of the deliberations, all voting members were polled and were in agreement with the findings and recommendations as written. There were no dissenting opinions, and therefore a dissenting opinion section is not included in this report.

## **Summary of Findings**

Per the appointment letter, the MIB was instructed to place the highest priority on determining corrective actions necessary to ensure public safety. Using evidence gathered from interviews and procedural/document reviews, the MIB conducted a Root Cause Analysis (RCA). Timelines, a fault tree (FT) and an event and causal factor tree (E&CFT) were developed, leading to the identification of 1 primary undesired outcome (PUO) that revealed 3 proximate causes, 14 significant intermediate causes, 12 observations, and 4 contributing factors. Six root causes were identified for the mishap at the organizational level under the PUO.

### **PUO      The NCT payload caused damage to private vehicles and nearly caused death or injury to the general public.**

During the course of the investigation, the MIB identified two additional undesired outcomes which will be addressed as "Secondary Undesired Outcomes (SUOs)." Even though addressing multiple undesired outcomes is not considered standard for reports, the MIB felt compelled to address these SUOs in this report.

### **SUO 1      NASA incurred significant loss of assets including the scientific payload, the airport**

**fence, and the costs associated with the failed launch attempt.**

**SUO 2 Contractor personnel were endangered when the payload inadvertently released from the launch head.**

This resulted in the addition of one root cause and one intermediate cause. Section 3 details the causes and how they were determined.

**Proximate Causes**

Three proximate causes were identified that produced the PUO. Had any of these causes been eliminated or modified, neither the Primary nor Secondary Undesired Outcomes would have occurred.

- P1 Proximate Cause: The NCT payload separated from the launch vehicle.**
- P2 Proximate Cause: The released payload was dragged downwind by the balloon.**
- P3 Proximate Cause: People in the general public were in the projected flight path.**

**Intermediate Causes**

An Intermediate Cause is an event or condition that created the proximate cause that, if eliminated or modified, would have prevented the proximate cause from occurring. The following significant Intermediate Causes were identified:

**I1 Intermediate Cause: WFF safety office did not perform rigorous hazard analysis.**

**I1-1 Recommendation**

WFF Safety Office should perform a complete hazard analysis in accordance with the NPR 8715.5 section 3.2 Range Safety Analysis. All phases of the balloon launch process should be considered. This hazard analysis should be validated by independent review.

**I2 Intermediate Cause: A barrier to keep the general public out of all dangerous areas throughout the launch process did not exist.**

**I2-1 Recommendation**

In each launch location, the BPO should ensure that dedicated safety personnel thoroughly examine(s) the potential for spectators or passers-by entering hazardous areas and implement barriers or controls to prevent entry during the launch process.

**I3 Intermediate Cause: No trained individual was in place to ensure public safety.**

**I3-1 Recommendation**

WFF Safety Office should assign a range safety officer who is properly trained in range safety and who does not have a role in ensuring mission success.

**I4 Intermediate Cause: The ground safety plan did not cover all relevant hazards and phases.**

**I4-1 Recommendation**

The WFF Safety Office should revise the balloon ground safety plan to cover all phases,

from inflation through recovery. The plan should address all hazards identified in the Hazard Analysis through appropriate restrictions and operational requirements.

**I5 Intermediate Cause: No complete and thorough standard procedure exists at CSBF to cover the launch process.**

**I5-1 Recommendation**

The BPO should develop a hazardous operating procedure to cover the launch process in accordance with NPR 8715.3, Section 3.8 Hazardous Operations.

**I5-2 Recommendation**

BPO should establish Launch Commit Criteria and flight rules.

**I5-3 Recommendation**

BPO should establish and document firm and unambiguous criteria for aborts during the launch phase.

**I6 Intermediate Cause: Launch crew training did not address failed launch attempts.**

**I6-1 Recommendation**

BPO should ensure that training for the launch crew covers the widest possible set of anomalous occurrences in the launch process including, but not limited to, failed launch attempts, breaches and near-breaches of the Hazard Zone, loss of payload control straps, loss of communication, and scenarios that would lead to an abort.

**I7 Intermediate Cause: Category A hazard area during launch phase was not well-defined.**

**I7-1 Recommendation**

WFF Safety Office should clearly and unambiguously define the Category A hazard area and should require that it be implementable in practice with visible markings.

**I8 Intermediate Cause: Terrain was rough and unimproved.**

**I8-1 Recommendation**

BPO should perform a cost, utility, and feasibility assessment for improving the terrain at Alice Springs Airport.

**I9 Intermediate Cause: CSBF has not analyzed the payload release system to establish the acceptable angular range of the balloon relative to the launch vehicle for launch attempts.**

**I9-1 Recommendation**

BPO should perform a thorough analysis of the payload restraint and release system to establish an acceptable angular range of balloon relative to crane for launch attempt.

**I10 Intermediate Cause: CSBF was not aware of hardware limitations that might give rise to a failure during a launch vehicle maneuver.**

**I10-1 Recommendation**

BPO should evaluate balloon launch hardware mechanisms through testing and review of



documentation and specifications to determine proper operating conditions and ranges. The results of this evaluation should then be used to define operating limits of launch hardware and specify abort criteria.

**I11 Intermediate Cause: The ground safety plan did not explicitly address the protection of the general public.**

**I11-1 Recommendation**

WFF Safety Office should specifically address how to deal with the general public in the ground safety plan.

**I12 Intermediate Cause: The BPO did not have sufficient insight or oversight into the technical aspects of CSBF's balloon launch process.**

**I12-1 Recommendation**

The BPO should become knowledgeable about the technical aspects of the launch process and gain an understanding of the hardware capabilities, limitations, operating bounds, and failure modes.

**I13 Intermediate Cause: WFF safety leadership did not provide appropriate oversight to WFF safety office's responsibilities with regard to the balloon program.**

**I13-1 Recommendation**

WFF safety leadership should ensure that WFF Safety Office is implementing an effective safety program that is applicable and consistent across the facility and for all contracts.

**I14 Intermediate Cause: WFF safety leadership did not thoroughly review balloon safety documentation.**

**I14-1 Recommendation**

WFF safety leadership should review WFF balloon safety documentation for clarity and accuracy.

**SUO I1 Intermediate Cause: WFF SMA did not perform systems safety analysis to identify hazards to assets.**

**SUO I1-1 Recommendation**

WFF Safety Office should perform a complete hazard analysis, in accordance with NPR 8715.5, section 3.2 Range Safety Analysis. All phases of the balloon launch process should be considered. This hazard analysis should be validated by independent review.

This recommendation is essentially identical to Recommendation I1-1. Note that the proper execution of NPR 8715.3 and 8715.5 will encompass the analysis of hazards to the assets and the development of procedures required for mitigation.

## **Contributing Factors**

A Contributing Factor is an event or condition that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence. The following Contributing Factors were identified:

**CF1 Contributing Factor: Restraint pin was not sufficiently lubricated.**

**CF1-1 Recommendation**

BPO should perform analysis and/or test to determine the relationship between pin lubrication and lanyard pull force to establish lubrication guidelines for proper operation.

**CF2 Contributing Factor: Secondary release mechanism did not exist.**

**CF2-1 Recommendation**

BPO should analyze, evaluate, and test the hardware to understand its capabilities and operating range, as well as to determine failures and associated sensitivities.

**CF3 Contributing Factor: Wind created a challenging environment.**

**CF3-1 Recommendation**

The BPO should establish firm, written criteria for wind limits and factor these into all go/no-go and abort criteria and any specific restrictions on a particular launch.

**CF4 Contributing Factor: The launch process is fragile**

**CF4-1 Recommendation**

A. Identical to **I5-1**

B. Identical to **I6-1**

**Root Causes, Intermediate Causes, Contributing Factor, and Recommendations**

Using FTA and E&CFT methodology, the board determined several root causes and established a number of recommendations that, if implemented, should prevent similar mishaps from occurring in the future. The following root causes were identified by the MIB:

A. *Wallops Flight Facility (WFF) Safety Leadership*

**R1 Root Cause: WFF safety leadership did not ensure complete flow down of agency requirements to protect the public.**

**R2 Root Cause: WFF safety leadership did not provide appropriate oversight to WFF implementation of safety requirements (WFF Safety Office and BPO as implementing organizations).**

**A-1 Recommendation**

WFF safety leadership should verify that all elements of the public (people in nearby populated areas, spectators, and passers-by) as well as NASA workforce, high-value equipment and property and the environment are protected from all credible hazards, identified by thorough, formal, hazard analysis, covering all phases of balloon operations from set-up through termination and recovery. (R1, R2)

**A-2 Recommendation**

WFF safety leadership should regularly verify, through a minimum annual audit, BPO's oversight of safety at balloon launches and the WFF safety office's activities to ensure

safety at balloon launches. (R2)

**A-3 Recommendation**

WFF safety leadership should review and become knowledgeable about all safety requirements and plans implemented for the balloon program and ensure the proper flow-down of safety requirements, including but not limited to NPR 8715.3 and NPR 8715.5 in order to protect the public, NASA workforce, high-value equipment, property and the environment. (R1, R2)

*B. WFF Safety Office*

**R3 Root Cause: WFF Safety office was not sufficiently knowledgeable about the details of the balloon launch process.**

**B-1 Recommendation**

WFF safety office should obtain expertise in the precise details of the balloon launch process through training and direct interaction to ensure their own capability to produce balloon ground safety documentation.

*C. GSFC Safety Leadership*

**R4 Root Cause: GSFC safety leadership did not verify or provide corrective action for flow-down of NASA requirements to protect the public.**

**C-1 Recommendation**

GSFC safety leadership should provide oversight to ensure that exhaustive measures are taken to safeguard the public in the balloon program with no less fervor than is imparted to other activities and programs at GSFC. The GSFC safety leadership should also provide oversight to ensure protection of the NASA workforce, high-value equipment, property, and the environment.

*D. Headquarters (HQ) Range Safety Program Office*

**R5 Root Cause: NASA Agency Range Safety Program failed to ensure corrective actions were accomplished from previous agency audits.**

**D-1 Recommendation**

NASA Agency Range Safety Program should exhaustively follow up on audit recommendations and report to senior management any conditions of inaction for safety-related concerns to prevent unsafe activities from continuing.

**D-2 Recommendation**

NASA Range Safety audit functions should be added to the NASA Safety Center Audits and Assessments responsibilities.

*E. BPO, WFF, GSFC, and HQ Science Mission Directorate (SMD)*

**R6      Root Cause: Reliance on past success has become a substitute for good engineering and safety practices in the balloon program.**

**E-1      Recommendation**

The BPO, WFF, GSFC, and SMD should avoid considering a particular mission success rate or lack of safety incidents to be a sign that activities have been or are currently safe.

**E-2      Recommendation**

NASA Safety Center (NSC) should generate a Case Study based on the common problem that the reliance on past success becomes a substitute for good engineering and safety practices.

**SUO R1      Root Cause: WFF Safety Leadership did not provide appropriate oversight to WFF asset safety.**

**Recommendation**

WFF safety leadership should review and become knowledgeable about all safety requirements and plans implemented for the balloon program and ensure the proper flow-down of all safety requirements, including but not limited to NPR 8715.3 and NPR 8715.5 in order to protect the public, NASA workforce, high-value equipment and property and the environment.

This recommendation is identical to Recommendation A-3.

**Other Observations and Recommendations**

**O1      Observation: The hanging heavy payload was not identified as a hazard.**

**O1-1      Recommendation**

WFF Safety Office should identify the hanging payload as a hazard and follow relevant standards and requirements for hanging payloads to ensure protection of personnel and the general public.

**O2      Observation: The Launch Director was not wearing protective equipment for his hands while pulling the launch lanyard.**

**O2-1      Recommendation**

WFF Safety Office should determine whether gloves or other Personal Protective Equipment (PPE) should be required for pulling the launch lanyard.

**O3      Observation: The audits conducted of WFF safety in 2002 resulted in recommendations that, if properly implemented, would have made the undesired outcome extremely unlikely.**

**O3-1      Recommendation**

WFF Safety Office should ensure that all actions from the 2002 independent assessment are closed out thoroughly and completely, in particular, Items 5, 6, 9, and 21 referenced from the document "WFF Range Safety Independent Assessment Response". GSFC safety leadership and the NSC should verify compliance with these recommendations.

**O4      Observation: Leaving the BPO and the CSBF responsible for classifying mishaps gives rise to sidestepping the requirements of a NASA incident response team.**

**O4-1      Recommendation**

WFF safety leadership should ensure that the mishap and contingency plans along with contracts associated with balloon campaigns adhere to requirements for an incident response team put forth in NPR 8621.1B.

**O5      Observation: The Balloon Ground Safety Plan (BGSP) identifies an institutional RSQA, but it's not clear whether this is a person, organization, or a virtual entity.**

**O5-1      Recommendation**

The RSQA for CSBF should be an approving authority and knowledgeable about the BGSP and should be responsible for ensuring its completeness and proper implementation in the field.

**O6      Observation: The Australia's Civil Aviation Safety Authority (CASA) operating permit contains an ambiguous definition of "the approved area" at the Alice Springs Airport.**

**O6-1      Recommendation**

The BPO should determine the full intention of CASA operating permits issued by the Australian government and be sure that they are properly implemented by CSBF and UNSW, along with stand-alone NASA range requirements.

**O7      Observation: Documented mishap response and recovery contingency plans do not meet the requirements of NPR 8621.1B.**

**O7-1      Recommendation**

WFF safety leadership should develop a mishap preparedness and contingency plan for BPO that adheres to the requirements put forth in NPR 8621.1B.

**O8      Observation: The requirements in 820-PG-8621.1.1B do not meet the Agency's requirements documented in NPR 8621.1B.**

**O8-1      Recommendation**

WFF needs to ensure that mishaps are appropriately classified and investigations are accomplished in accordance with NPR 8621.1B. Any program level procedures for mishap investigation and reporting should be coordinated with GSFC Safety and Mission Assurance (Code 300) and if necessary with OSMA to ensure they meet the Agency level requirements.

**O9      Observation: The safety organization at WFF is not independent from projects and lacks the direct SMA reporting path that exists at GSFC at Greenbelt Md.**

**O9-1      Recommendation**

GSFC should establish an organizational structure for safety that is consistent across Goddard's Greenbelt and Wallops facilities, where the entire chain of the safety organization below the GSFC Center Director is independent of the projects, as is currently

in place for the Code 300 organization at GSFC at Greenbelt, MD.

**O-10      Observation: CSBF personnel seemed unaware of a number of operational hazards and constraints.**

**O10-1      Recommendation**

The WFF Safety Office should ensure CSBF completes a job hazard analysis and that CSBF personnel have appropriate hazard awareness training for all the hazards associated with each launch operation.

**O-11      Observation: Members of the CSBF launch crew were not wearing hard hats during the launch operation as required by Section 4.1 of the Ground Safety Data Package.**

**O11-1      Recommendation**

The WFF Safety Office and the BPO should assign an independent, trained safety officer for each launch. Both the safety officer and the campaign manager should ensure that all designated hazard controls, including PPE are implemented for each launch operation.

**O-12      Observation: The Corrective Actions from a previous balloon close call in 2000 were not implemented for this program despite their apparent applicability (use of protective cage and PPE).**

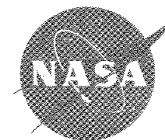
**O12-1      Recommendation**

The BPO and the WFF Safety Office should ensure that all applicable lessons learned relating to balloon launches, including IRIS reports are examined and if applicable, that the corrective actions are implemented across the balloon program.

## 1.0 Charter and Response

### 1.1 Transmittal Letter

National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, MD 20771



September 7, 2010

Reply to Attn of: 350

TO: 100/Director

FROM: 350/ Nuclear Compton Telescope (NCT) Balloon Launch Mishap Investigation Board

SUBJECT: Final Mishap Investigation Board (MIB) Report of the Nuclear Compton Telescope (NCT) Balloon Launch Mishap

Reference your memo dated May 12, 2010, which established the Mishap Investigation Board for the Nuclear Compton Telescope Balloon Launch High Visibility Type B Mishap that occurred on April 28, 2010, and defined the Board's responsibilities.

The investigation was conducted in accordance with NPR 8621.1 "NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping." The final report of the Mishap Investigation Board's activities, findings, and recommendations are enclosed.

A handwritten signature in cursive script, reading "Michael L. Weiss".

Michael L. Weiss

MIB Chair

Enclosure





## 1.2 Appointment Letter

National Aeronautics and  
Space Administration  
**Goddard Space Flight Center**  
Greenbelt, MD 20771



May 12, 2010

to Attn of:

100

TO: Distribution

FROM: 100/Director

SUBJECT: Formation of a Mishap Investigation Board (MIB) to Investigate the Aborted  
Launch of the Nuclear Compton Telescope (NCT) Mission

On April 28, 2010, the scientific balloon launch from Alice Springs, Australia in support of the Nuclear Compton Telescope (NCT) was declared a mishap. The payload got dragged along the ground, impacting a SUV, and nearly injuring spectators. While no injuries were reported, the payload impacting the vicinity of personnel represents a failure of the safety operations process.

An assessment of NCT payload damage is underway. Based upon the Balloon Program basis of accepted risk for these types of missions, the investigation will proceed as a high visibility investigation given property loss (other than payload) and potential to personnel injury. Due to the severity of the proximity to the aborted launch to the spectators, the mishap investigation will place a high priority in addressing corrective actions needed to ensure public safety in future launch operations.

All pertinent equipment and documentation has been impounded. There will be no other NASA balloon launches until GSFC understands the failure, understands the required corrective actions and I am assured of the safety of our people and the public.

In accordance with the NPR 8621.1B, I am establishing the Australia Balloon MIB to gather information; analyze the facts; identify the proximate cause(s), root cause(s) and contributing factors relating to the mishap; and to recommend appropriate actions to prevent a similar mishap from occurring again. The chairperson and members of the MIB are listed in the enclosure. The Chairperson of the MIB will report to me on all aspects regarding this investigation.

The MIB will:

- Obtain and analyze whatever evidence, facts, and opinions it considers relevant.
- Conduct tests and any other activity it deems appropriate.
- Interview witnesses and receive statements from witnesses.
- Impound property, equipment, and records as considered necessary (consistent with the agreements with the international partners and contractors).

- Develop a timeline.
- Determine the proximate cause(s), root cause(s), and contributing factors relating to the mishap.
- Develop recommendations to prevent similar mishaps.
- Review launch procedures to ensure all steps were appropriately completed.
- Review the proximity of spectators to the launch, the actions taken to ensure public safety during the mishap, and corrective actions needed to ensure public safety at remote sites in the future.
- Review associated mechanical and electrical designs to assess adequacy for launch operations.
- Assess prelaunch planning and operations testing that was conducted and the procedures that were used for adequacy in preventing this type of mishap.
- Provide recommendations and lessons learned to be incorporated into the development of a Corrective Action Plan by the Balloon Program Office.
- Provide a final written report that will conform to all requirements in the referenced NPR.

The Chairperson will:

- Conduct MIB activities in accordance with the requirements in NPR 8621.1.
- Establish and document, as necessary, rules and procedures for organizing and operating the MIB, including any subgroups, and for the format and content of oral or written reports to and by the MIB.
- Designate any additional representatives, advisors, consultants, experts, liaison officers, or other individuals who may be required to support the activities of the MIB and define the duties and responsibilities of those persons.
- Designate another voting member of the MIB to act as chairperson in his or her absence.
- Document meetings and retain records.

The WBS to be used for charging hours in support of this investigation is 911542.06.01.01. The travel WBS is 911542.01.02, SCEX222010D.

The Columbia Scientific Balloon Facility (CSBF) contractor shall provide additional ad-hoc support as requested by the board. The Balloon Program Office will provide an in brief with copies of the relevant documentation to the MIB. The MIB will be supported by Code 820 and the Physical Science Laboratory/CSBF contractor personnel, as required.

MIB will provide a preliminary written report containing the proximate cause(s), root cause(s), and recommendation(s), and submit it to me by May 28, 2010. The MIB is solely responsible for the implementation of this review.



Robert Strain

Distribution:

100/Mr. Strain  
100/Mr. Obenschain  
100/Mr. Figueroa  
300/Dr. Leitner  
300/Ms. Bruner  
321/Ms. Hamilton  
350/Mr. Lopez  
350/Ms. Cutler  
455/Mr. Weiss  
500/Mr. Nelson  
598/Mr. Simpson  
800/Mr. Wrobel  
800/Ms. Bass  
800/Mr. Purdy  
803/Ms. Smith  
803/Mr. Patterson  
803.1/Mr. Leibig  
820/Ms. Gramlich  
820/Mr. Gregory  
820/Mr. Pierce  
HQ/Science Mission Directorate/Astrophysics Division/Dr. Jones  
HQ/Science Mission Directorate/Astrophysics Division/Mr. Sistilli  
HQ/Science Mission Directorate/Astrophysics Division/Dr. Morse  
HQ/Office of the Chief Engineer/Dr. Ryschkewitsch  
HQ/Office of Communications/Mr. Jacobs  
HQ/Office of Communications/Ms. Dickey  
HQ/Office of General Counsel/Mr. Wholley  
HQ/Office of General Counsel/Mr. Thomas  
HQ Office of International & Interagency Relations (OIIR)/Mr. O'Brien  
HQ Office of International & Interagency Relations (OIIR)/Mr. Basha  
HQ/Office of Legislative & Intergovernmental Affairs (OILA)/Mr. Statler  
HQ/Office of Legislative & Intergovernmental Affairs (OILA)/Mr. Flaherty  
HQ/Associate Administrator/Mr. Scolese  
HQ/Office of Safety and Mission Assurance/Mr. O'Connor  
KSC/Mr. Schumann

NSC/Ms. French  
PSL/Mr. S. Hottman  
PSL/CSBF/Mr. Ball  
PSL/CSBF/Mr. Orr

### 1.3 Signature Pages

#### Investigating Authority Signatures

To the best of our knowledge the report contents are accurate and complete, and we concur with the documented findings and recommendations.



**Michael Weiss**  
**Chairman**  
**Code 455**  
**Goddard Space Flight Center, MD**



**Gerald Schumann**  
**Alternate Chair**  
**SA-F**  
**Kennedy Space Center, FL**



**Carol Hamilton**  
**Member - Human Factors**  
**Code 321**  
**Goddard Space Flight Center, MD**



**Joel Simpson**  
**Member - Technical**  
**Code 598**  
**Goddard Space Flight Center, MD**



**Jesse Leitner**  
**Member - Safety**  
**Code 300**  
**Goddard Space Flight Center, MD**

### **Ex Officio Signature**

I assure the following:

- The investigation was conducted in conformance with NASA policy and NASA Procedural Requirements 8621.1,
- The investigation process is fair, independent, and non-punitive,
- The mishap report contains all the required elements,
- Adequate facts have been gathered and analyzed to substantiate the findings,
- The mishap report accurately identifies the proximate cause(s), root cause(s), and contributing factor(s),
- The recommendations reasonably address the causes and findings, and
- Each recommendation can be tied to a finding.

I also concur with this report.

A handwritten signature in cursive script, appearing to read "Kristie French", written in black ink.

**Kristie French**  
**Ex-Officio**  
**NASA Safety Center**

## **Advisors' Signatures**

I sign this report indicating that the report sufficiently meets the legal requirements for NPR 8621.1B.



**Dan Thomas**  
**Legal Advisor**  
**Office of the General Counsel**  
**NASA Headquarters**

I sign this report indicating that it is consistent with the policies and procedures in my functional area.



**Patrick Besha**  
**International Affairs Advisor**  
**OIIR**  
**NASA Headquarters**

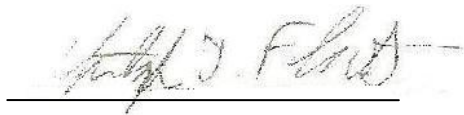
I sign this report indicating that it is consistent with the policies and procedures in my functional area.



**Beth Dickey**  
**Public Affairs Advisor**  
**Office of Communications**  
**NASA Headquarters**

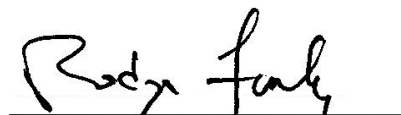


I sign this report indicating that it is consistent with the policies and procedures in my functional area.

A handwritten signature in dark ink, appearing to read "Chris Flaherty", written over a horizontal line.

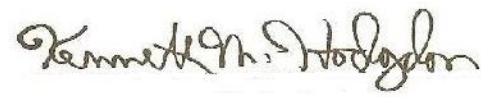
**Chris Flaherty**  
**Legislative Affairs Advisor**  
**Office of Legislative and Intergovernmental Affairs**  
**NASA Headquarters**

I sign this report indicating that the report is technically correct in my functional area.

A handwritten signature in dark ink, appearing to read "Rodger Farley", written over a horizontal line.

**Rodger Farley**  
**NASA, Code 543**  
**Goddard Space Flight Center, MD**

I sign this report indicating that the report is consistent with the policies and procedures in my functional area and that any ITAR information and EAR information has been identified and marked as non-releasable to the public (e.g., NASA Sensitive But Unclassified).

A handwritten signature in dark ink, appearing to read "Kenneth M. Hodgdon", written over a horizontal line.

**Kenneth M. Hodgdon**  
**NASA, Export Control Advisor**  
**NASA Headquarters**



## 2.0 Overview

In 1981, NASA began conducting balloon operations at the Alice Springs airport. Approximately 50 NASA balloon missions have been launched there since that time. Before NASA's involvement, other organizations had conducted balloon launch operations in Australia for approximately 20 years.

NASA's Balloon Program Office (BPO) is physically located at Goddard Space Flight Center's (GSFC's) Wallops Flight Facility (WFF) on Wallops Island, Virginia. The BPO manages all balloon program activities and programmatically reports to the Astrophysics Division within NASA's Science Mission Directorate (SMD) at NASA Headquarters. The New Mexico State University, Physical Sciences Laboratory's Columbia Scientific Balloon Facility (CSBF) is under contract to the BPO to conduct balloon operations at all launch facilities, including the Alice Springs Balloon Launch Facility at Alice Springs Airport in Australia (Figures 1 through 3). The University of New South Wales manages the Alice Springs Balloon Launch Facility under the direction of the Site Director (SD). The CSBF Launch Director (LD), who reports to the CSBF Campaign Manager (CM), directs launch operations.



**Figure 1. Central Continent Location of Alice Springs, Australia**



**Figure 2. Location of Airport in Relation to Alice Springs**



**Figure 3. NW End of Alice Springs Airport**



## 2.1 Balloon Launch (General)

Balloon flights offer unique opportunities to obtain scientific data. The launch concept involves suspending the science payload from a mobile launch crane using a plate retained with safety restraint cables.

One end of the plate is affixed to the balloon flight train by attaching cables, a parachute, termination components, and the balloon. The balloon geometry is initially constrained by a collar to keep the balloon from becoming a spinnaker sail when it first takes flight. On launch day, the payload and balloon components are laid out once the LD verifies favorable weather conditions. The collar-constrained balloon bubble is inflated with helium. Once the balloon is launched, the LD maneuvers the launch crane so that the balloon passes directly overhead.

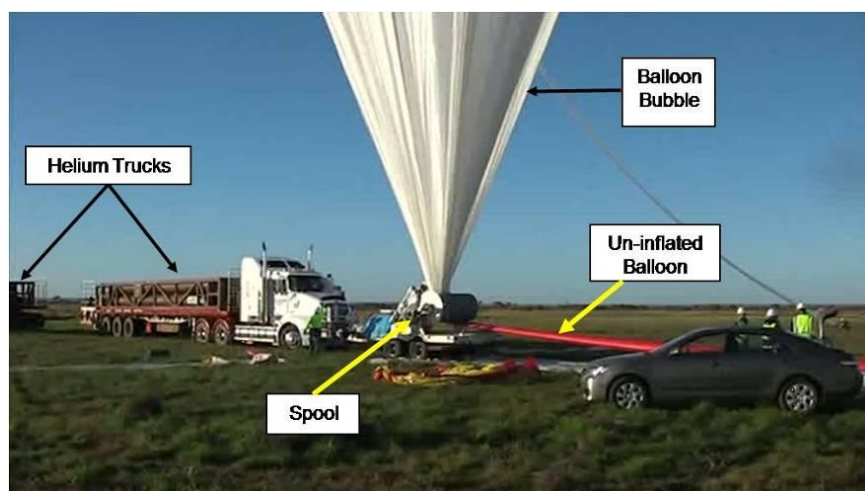
Launched by releasing the spool, a balloon achieves the direct overhead position generally in about 25 to 35 seconds. Ideally, when the balloon is overhead, the LD pulls down on a release lanyard, which in turn releases the payload from the launch vehicle.

The balloon launch process employs several components: the spool trailer which holds the balloon through layout, inflation, and release; up to two standard helium trailers to inflate the balloon; and the launch vehicle. The hardware setup is shown in Figure 4.

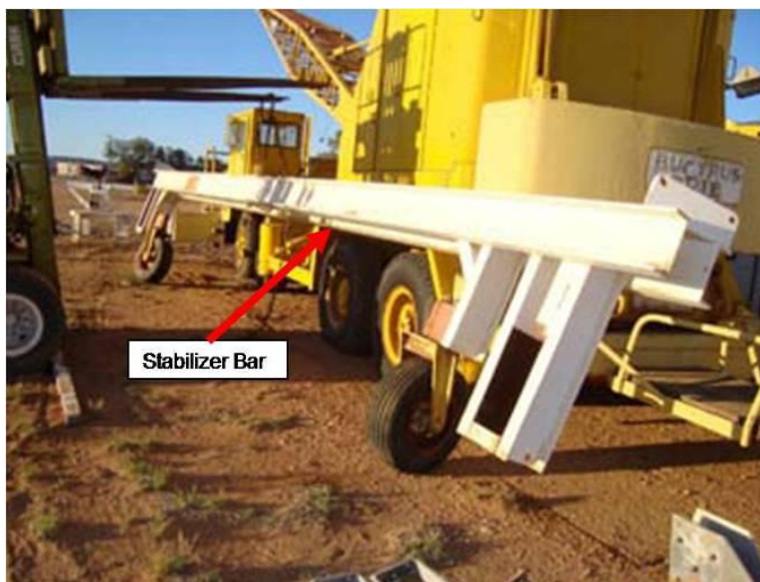
The launch vehicle is a mobile crane rented by CSBF. CSBF specifies vehicle requirements to prospective suppliers in a request for quotation (RFQ). (Refer to Appendix M.) The requirements stated in the RFQ are as follows:

- Crane vehicle is in very good mechanical condition and has good acceleration.
- Wheelbase length from the front axle to the rear axle is a minimum of about 20ft.
- Total vehicle weighs a minimum of 50 tons.
- Crane lifting capability is 59 tons.
- Crane boom extends out from the front of the vehicle by at least 10.5 ft when at a height of ~40 ft from the ground.

The crane must be modified to hold and release a payload. Stabilizers are added to the crane so it can be moved with the boom in an upward position. This is done by fitting three pieces of hardware onto the crane: (a) a pair of stabilizer bars equipped with swivel wheels connected to outriggers parallel to the crane body (Figure 5), (b) a specially designed launch head unit fixed to the end of the crane boom, and (c) a platform with railings on the front of the vehicle for the LD and payload launch assistant allowing access to the tag lines and the release lanyard.

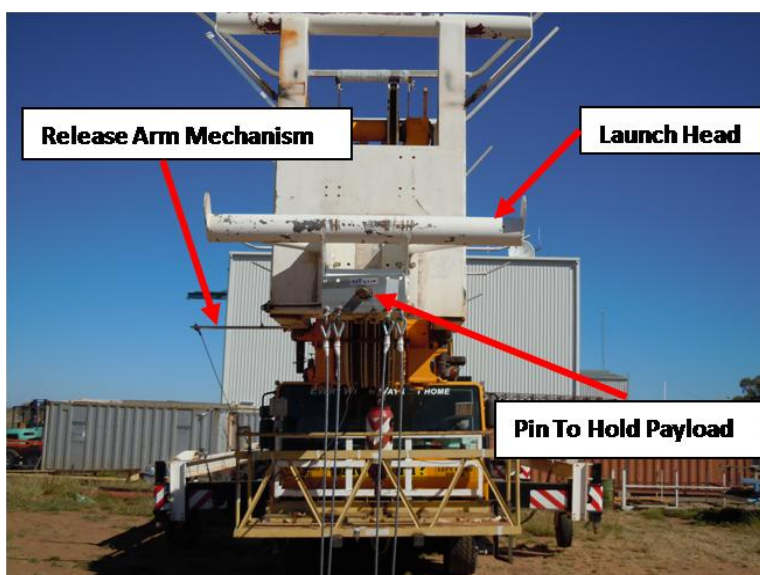


**Figure 4. Balloon Bubble and Spool**



**Figure 5. Stabilizer Bar**

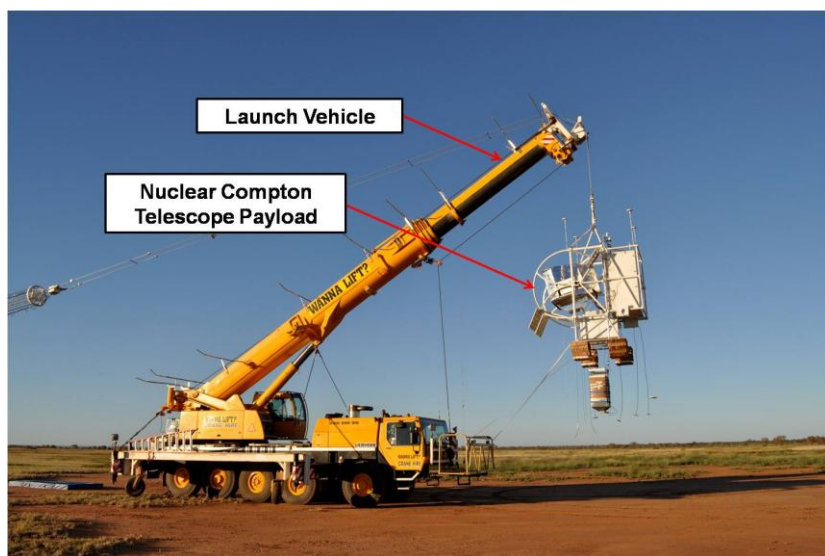
The launch head is designed to be pinned to the crane head employing the existing pins and pin holes used for the light boom extension. The scientific payload is suspended from the launch head by a pin that points away from the crane boom. At launch, the launch head unit releases the payload with a release arm mechanism (Figure 6).



**Figure 6. Launch Head Attached to Crane Boom**

## **2.2 Balloon Launch Process**

On the day of flight, given favorable weather conditions, CSBF support personnel use the launch vehicle to pick up the payload (Figure 7).



**Figure 7. Launch Vehicle With Payload**

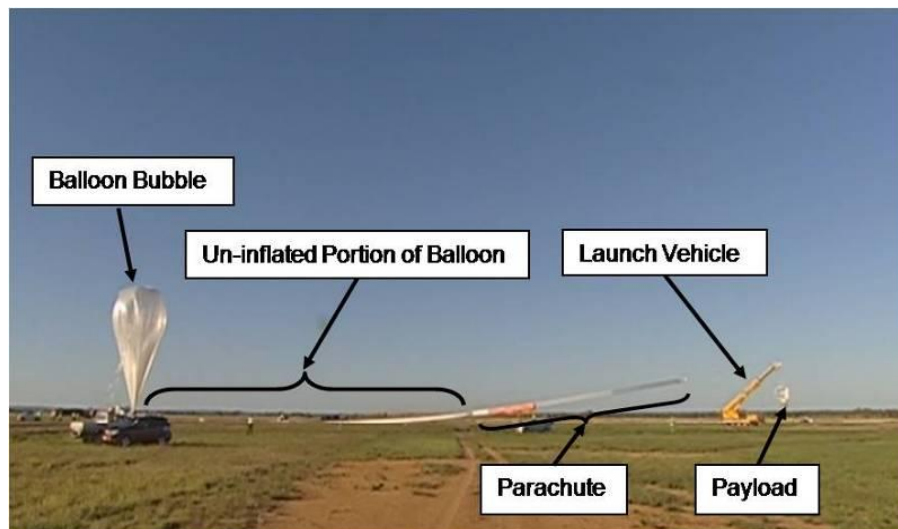
CSBF and the science team perform preflight electronics checks and then interface the CSBF balloon hardware with the scientific equipment. The flight line crew then places a protective ground cloth the

entire length of the flight train and balloon to prevent ground contact damage to the flight train equipment, parachute, and balloon. The parachute stream is arranged onto the ground cloth and checked. After the flight train and parachute are extended at length, the balloon is put down and attached to the parachute as shown in Figure 8. The CSBF flight crew then performs the flight line checkout.

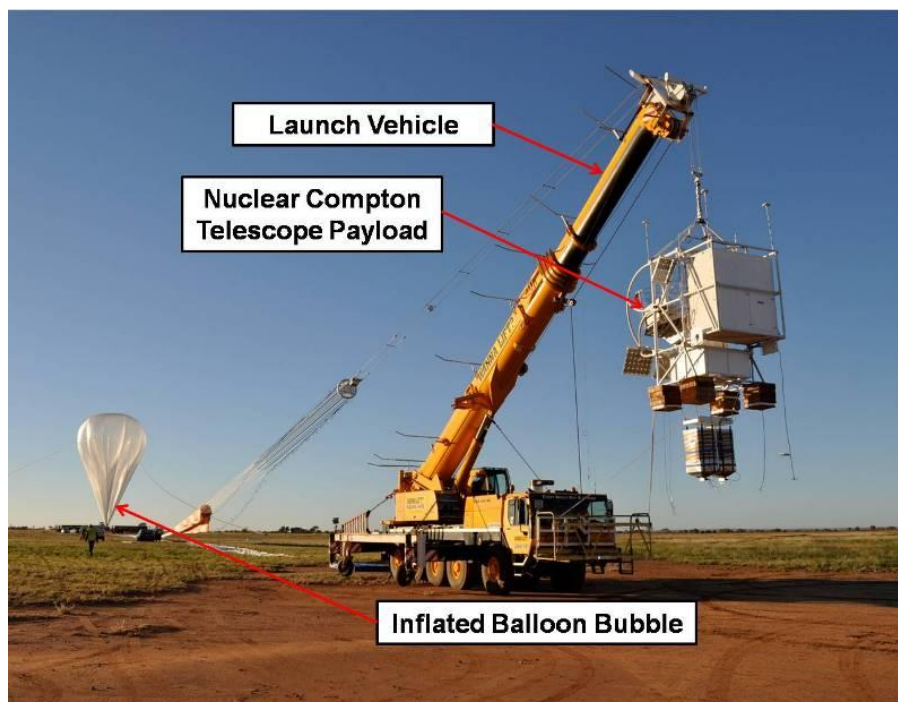


**Figure 8. Balloon Being Laid Out**

NASA uses a standard process, called the “dynamic launch,” for launching a large stratospheric balloon system. Basically, a large spool holds the top portion of the balloon (called the “bubble”) in place while it is filled with the appropriate amount of helium. The helium acts as a lifting gas, displacing the heavier gas mixture of air. The launch vehicle holds the payload in place downwind of the balloon’s inflated top portion. The basic configuration for launch is shown in Figures 9 and 10. Details of the balloon and spool area are shown in Figure 11.

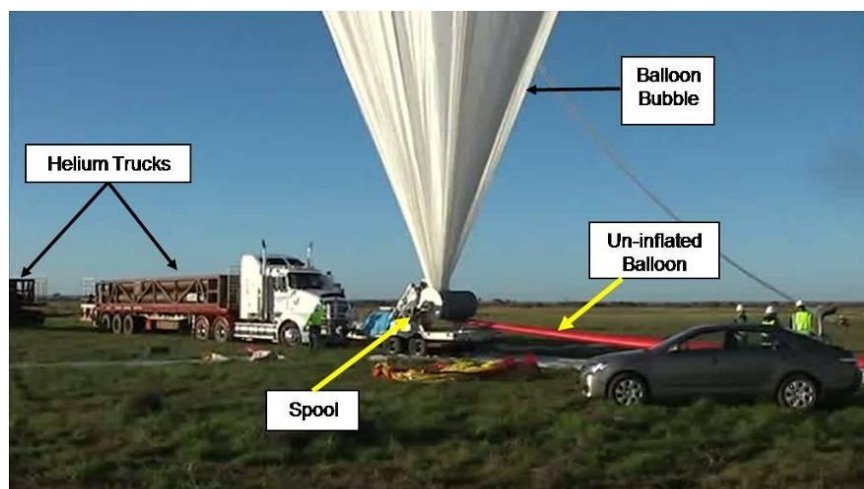


**Figure 9. Balloon Configuration for Launch**



**Figure 10. NCT Launch Configuration**





**Figure 11. Balloon Bubble and Spool**

Because helium gas expands as the balloon rises in the atmosphere, only a portion of the balloon, the bubble, is inflated. The bubble is restrained by passing the uninflated “rope” section of the balloon under the spool (Figure 11). The uninflated portion is protected during the inflation process by an extra layer of film known as “red wrap.” The spool trailer is connected to the helium truck vehicle to provide necessary anchoring. The payload end of the system is restrained at the launch vehicle.

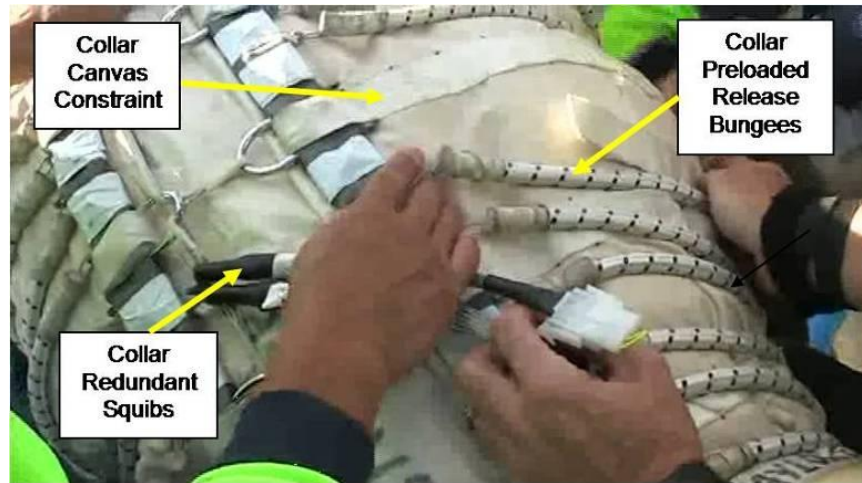
When the balloon and payload are cleared for launch and the LD is ready, a release handle (Figure 12) on the spool is activated, allowing the balloon bubble to rise rapidly. Initially, the lifting force is many times the mass of what it is lifting because the launch vehicle is supporting the payload weight and much of the balloon and flight train is on the ground.



**Figure 12. Spool Release Handle**

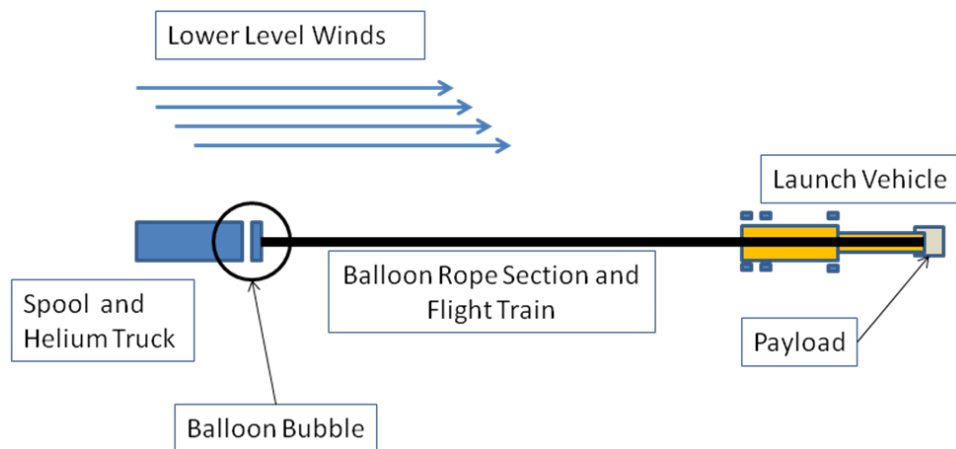


After release, the bubble size is constrained by a collar device to prevent the bubble from “sailing” as a result of its rapid forward progress. The collar is released through remote command when the balloon flight train is nearly vertical above the launch vehicle. Collar release can occur before or after the payload is released from the launch vehicle. Collar installation is shown in Figure 13.



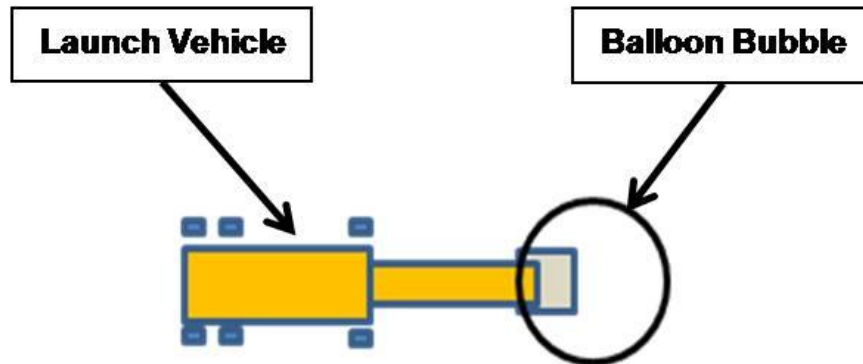
**Figure 13. Collar Installation**

Since the balloon system layout is arranged with the local wind direction, the balloon bubble and flight train rise up over the launch vehicle and continue with the wind. The launch vehicle then is moved so that the balloon is kept close to directly overhead or slightly ahead of the launch vehicle until the launch release is accomplished. Figure 14 depicts the balloon layout aligned with the lower level winds.



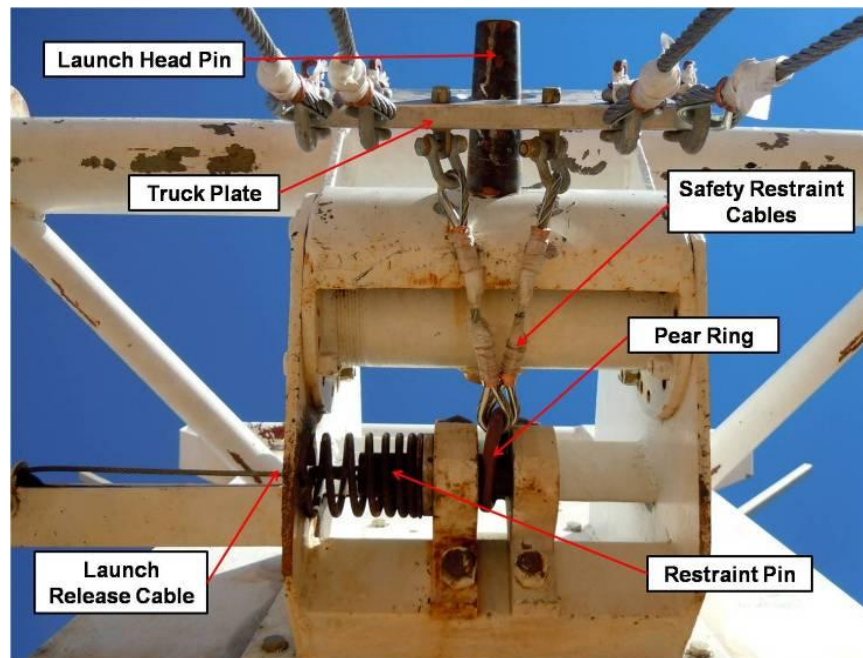
**Figure 14. Balloon Layout Aligned With Lower Level Winds**

The desired position for a release is shown in Figure 15.



**Figure 15. Desired Balloon Position for Release**

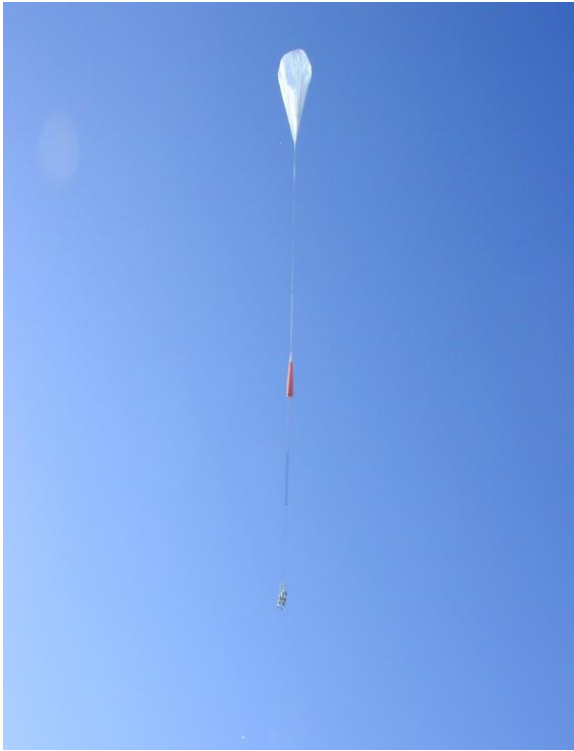
After the balloon is in the proper position, the LD releases the payload by pulling on the release cable. This in turn pulls on a spring-loaded restraint pin that restrains the truck plate on the launch head pin through two safety restraint cables as shown in Figure 16. The truck plate, which is attached to the payload and the balloon train, can then slide off of the launch head pin.



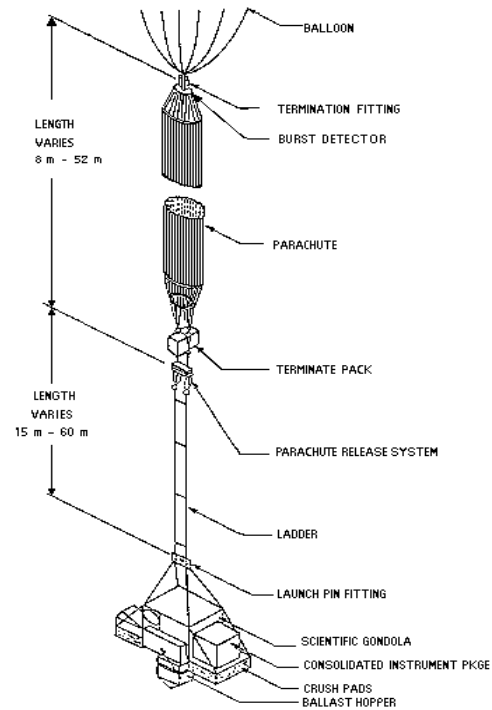
**Figure 16. Launch Head Components**

The balloon and its payload then begin the ascension to float altitude (Figure 17). Data collection and command and control are maintained continuously from prelaunch until the end of flight. Termination is accomplished using a Payload Parachute Recovery System (PPRS), which is rigged unpacked and in

line with the flight train (Figure 18) and attached to the balloon's base. The recovery parachute deploys immediately upon command activation, initiated at the flight termination. The balloon, now physically detached from the parachute and payload, descends back to earth. The balloon, parachute, and payload are then recovered.



**Figure 17. Balloon Ascending**



**Figure 18. Flight Train Components**

### 2.3 Description of Mishap

On April 29, 2010, personnel from the CSBF, on behalf of NASA, attempted to launch the NCT at the Alice Springs Balloon Launch Facility, Alice Springs Airport, Australia (Figures 1 through 3). The University of New South Wales manages the Alice Springs Balloon Launch Facility under the direction of the SD. The CSBF LD, who reports to the CSBF CM, directs launch operations. On launch day, weather conditions were deemed acceptable throughout launch setup operations. Preparations for launch and flight line setup were nominal. Balloon inflation was nominal as was spool release. The payload did not release despite repeated attempts to activate the launch mechanism. The LD attempted to catch back up with the balloon for another launch attempt but ran out of room at the airport fence. The LD realized that spectators behind the fence were in harm's way from the falling balloon train if the abort command were to be initiated and decided to back the launch vehicle away from the fence. While the launch vehicle (crane) was being positioned for abort procedures, the payload inadvertently separated from the launch vehicle. The airborne balloon dragged the NCT payload along the ground. The payload breached the airport security fence and struck a privately owned vehicle. Another vehicle

suffered cosmetic damage. Several spectators ran for safety after seeing the payload separated from the crane. While the payload was being dragged, the mission was aborted by commanding the balloon to separate from the parachute. The balloon came to rest approximately 0.25 mile downwind from the site of separation.

## **2.4 General Events Occurring Before the Mishap**

The MIB derived the facts provided in this section from existing documentation, mishap site visits, witness interviews, photographic and video evidence, and data supplied by the CSBF and NASA's BPO. These supporting data are further described in Section 3.0.

Three missions were planned during the March/April/May campaign of 2010. On April 15, 2010 Greenwich Mean Time (GMT), the Tracking and Imaging Gamma Ray Experiment (TIGRE) mission was successfully launched. TIGRE conducted science for 2 days and 9 hours before the planned termination and recovery on April 18, 2010.

After the launch of TIGRE, launch preparations were made for the NCT Mission. The NCT Principal Investigator (PI) declared the science payload flight-ready on April 14. Between April 19 and 28, the crew and PI staff were on station for potential launch attempts, but were unable to proceed because of unfavorable weather conditions.

On April 29, the crew and PI arrived for launch at approximately 2 a.m. The LD and campaign manager, after consulting with the meteorologist, decided that weather conditions were favorable for launch. Atmospheric conditions were continuously monitored by the meteorologist who was obtaining data from pilot balloons (PiBals), Australian weather data sources, and other accessible data sources. Between 2 a.m. and 6 a.m., the payload was prepared for flight, picked up by the launch crane, ballast added, and the payload was taken, along with the balloon, to the launch area on the northwest end of Alice Springs Airport. The LD decided on a layout orientation of 110 degrees based on continuous PiBal data (Figure 19). The balloon layout, flight train connections, electrical tests, and other standard launch preparations continued nominally. At approximately 6:43 a.m., balloon inflation commenced.



On April 29, 2010 at 2:18 a.m. ACT, the mission meteorologist performed a pilot balloon (PiBal) sounding to determine wind conditions at the launch site. By 2:30 a.m., the rest of the CSBF launch team had reported to the Alice Springs Airport Balloon Facility to prepare for the NCT launch attempt. A second PiBal run was conducted at 2:59 a.m., yielding a wind profile that led the LD to decide to use a balloon layout direction of 110 degrees. Concurrently, the NCT payload was picked up and transported to the launch vehicle. The launch vehicle picked up the payload by about 3:00 a.m. A half hour later, the launch vehicle with payload and the balloon were transported to the flight line area.

At about this time, the LD noticed spectators downwind along the projected path of the balloon and requested over the open voice line (hand-held radios used in the field) that these persons be moved. The launch team used a tethered PiBal on the face of the launch vehicle to indicate wind direction between 800 and 1,000 ft. The tethered PiBal indicated that the balloon would drift slightly north as it took flight. At this time, an off-duty CSBF crew member (CCM) was observing the launch from outside the fence area and heard the request to move the spectators over his hand-held radio. The CM also responded by calling the SD and relaying the request to relocate the spectators. The SD then

requested his deputy to perform the relocation. The deputy SD proceeded to a position along the fence slightly south of the projected flight path and requested persons in two vehicles to move further north toward facility buildings. Soon afterward, the aforementioned CCM volunteered to move spectators that were located slightly north of the projected flight path to what he thought was a safer location which was south from the spectators' current positions. One spectator told the CCM when asked to relocate further south that he had just been asked to move north. Specific direction regarding safe locations was not provided to the individuals who relocated spectators, and the resulting actions actually relocated spectators into the eventual path of the balloon and launch vehicle.

By 7:40 a.m., another PiBal run was performed indicating the wind had shifted slightly and was now more from the south, at about 121 degrees. Inflation was completed at 7:50 a.m. and the operational positions of Collar 1 and Collar 2 were manned. Also, at about 7:50 a.m., the SD requested Air Traffic Control (ATC) clearance for launch from Melbourne. (Because of the time of this particular launch attempt, the Alice Springs tower was closed.) ATC directed the SD to hold because of local air traffic in the area. Approximately 10 minutes later, the SD received launch clearance from ATC.

### **Key Events (from the time of spool release)**

The critical events directly leading to the mishap (Key Events) are described here and coincide with the detailed timeline (Table 2).

In many of the subsequent portions of this report, the times will refer to the elapsed time from the moment of the spool release. This is referred to as the "Phased Elapsed Time" or PET. The reference time of spool release is PET=0.0. Times referenced are based on a review of all factual data collected from detailed interviews and pertinent documentation, and numerous videos and photographs. The accuracy of the relative times presented is limited to about 2 seconds. A detailed chronological timeline was developed and is available in Section 3.5.

**Key Event 23:** The launch spool was released at approximately 8:05:19 a.m. (**PET=0**). The balloon rose in a nominal fashion and took about 5 sec to lift the flight train from the ground.

**Key Event 24:** At about **PET=10 sec**, the LVD, under direction from the LD, began driving forward (WNW) and to the right (NNE) in a sweeping right turn as the balloon continued to rise and be pushed to the north of the layout line by the lower level winds.

**Key Events 25 and 26:** At **PET=37 sec** and **39 sec** the primary and secondary calls were made to release the collar that prevents the balloon bubble from "sailing" during the early rise phase. Both collar callers observed nominal collar release. The CM was serving as Collar 2. Both collar callers were required to observe the balloon's flight and collar release.

**Key Event 27:** At **PET=45 sec**, the sweeping right turn was completed. After finishing the sweeping right turn, the launch vehicle was located approximately 200 ft to the right of the original 110 degree flight layout.

**Key Events 28 and 29:** The LD instructed the LVD to turn left in line with the balloon direction. At **PET=45 sec** the launch vehicle momentarily came to a stop while beginning a left turn to realign with



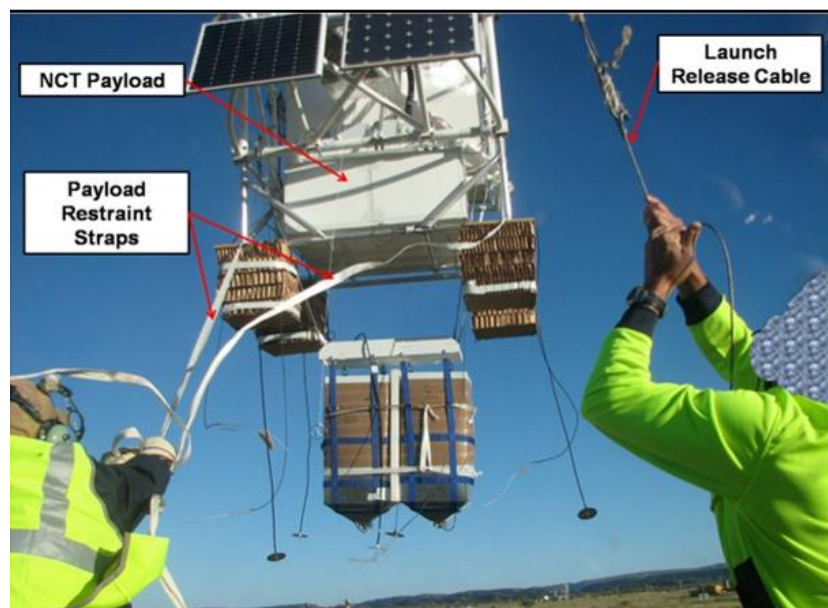
the balloon's flight direction. At **PET=46 sec**, voice confirmation of "collar off" occurred. At about **PET=47 sec**, the vehicle began moving again and then completed the left turn. In summary, the completion of the nearly 90-degree sweeping right turn, a NNE traverse of about 200 ft, then a nearly 90-degree left turn put the launch vehicle back on a path nearly parallel to the original layout line.

*Assuming the Category A Hazard Area (as defined in the OF610 CSBF Ground Safety Plan) is attached to the launch vehicle and dynamically moves with the launch vehicle, then the Category A Hazard Area breached the location of spectators at the perimeter fence at PET=48 sec (approximately 3 sec after initiating the left turn).*

**Key Event 30:** At **PET=62 sec**, the vehicle lost traction and slowed down. It quickly regained traction and resumed its forward motion. The launch vehicle proceeded along a path parallel to the layout direction.

*Assuming the Category A Hazard Area is fixed relative to the original launch vehicle position, then at PET=79 sec, the launch vehicle breached the Category A Hazard area.*

**Key Event 32:** Approximately 7 sec later, at **PET=86 sec**, the LD instructed the LVD to slow and stop to attempt a launch. When the LD pulled on the launch release lanyard, the launch restraint pin did not release the payload. During this launch attempt, the payload swung out away from the launch vehicle as a result of its inertia, and a team member riding on the launch vehicle with the LD lost hold of the payload controlling straps. The payload continued to swing as the LD tried again to pull the launch release lanyard to release the payload. Again, the payload did not release. The launch attempt, as viewed from the front of the launch vehicle, is shown in Figure 20. By about PET=90 sec, the vehicle was at a complete stop.



**Figure 20. Actual NCT Launch Attempt**

After unsuccessful attempts to release the payload, the LD instructed the LVD to proceed forward to try to “catch” the balloon.

**Key Event 39:** At about **PET=105 sec**, the launch vehicle arrived at the perimeter fence and stopped. The LD realized that the mission would have to be aborted, but because spectators were in the flight path, did not order an abort. After several seconds at the fence, the LD ordered the vehicle to be backed away from the fence. Spectator locations during this event are shown in Figure 21.

**Key Events 41 through 43:** The vehicle began backing away at **PET=118 sec** and continued backing until about **PET=150 sec**. At this time, the vehicle no longer had traction to continue backing as a result of the tires slipping in the loose soil. At this point, the launch vehicle was still about 150 ft beyond the Category A Hazard Area (fixed interpretation). The LD instructed the LVD to proceed forward and make a left turn in an attempt to move the system away from the spectators. Spectator locations during this event are shown in Figure 21.

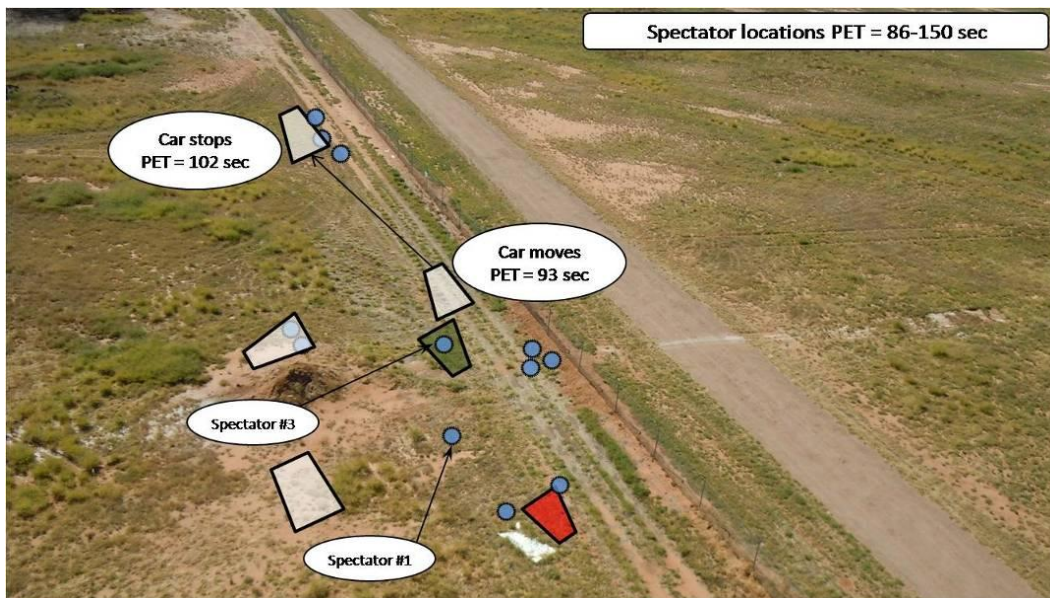


Figure 21. Spectator Location at PET 86-150 Seconds

**Key Event 44:** During the left turn, the payload inadvertently released from the launch vehicle at **PET=171 sec**. The balloon pulled the payload downwind, where it breached the Airport security fence and continued moving towards spectators’ cars and spectators who were in the path of the payload’s motion. Spectators were able to run to safety.

During the dragging event, a call was made by the CM to abort the balloon. The mishap site and spectator locations at the time of the mishap are shown in Figures 22 through 25.



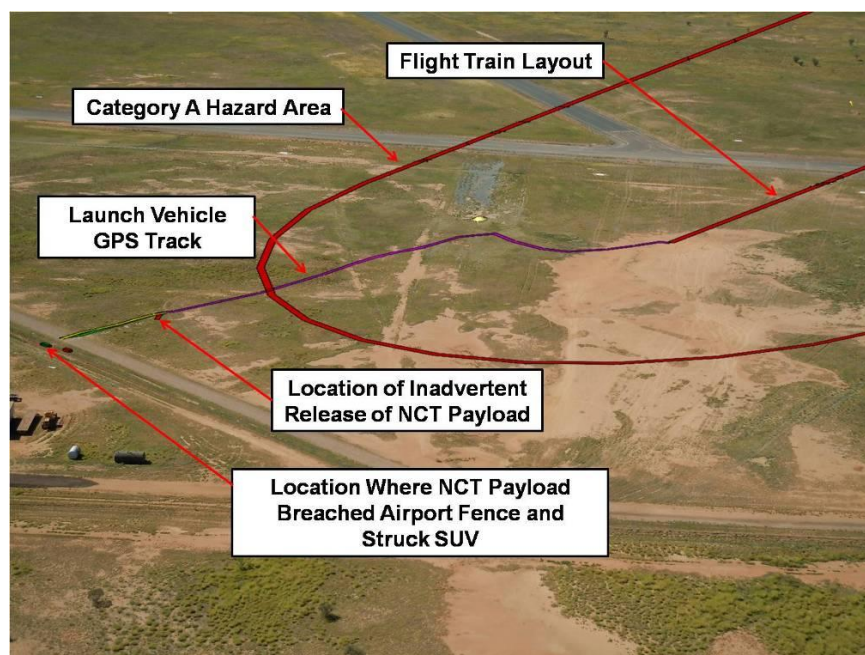


Figure 22. Location of Mishap Site at the Alice Springs Airport

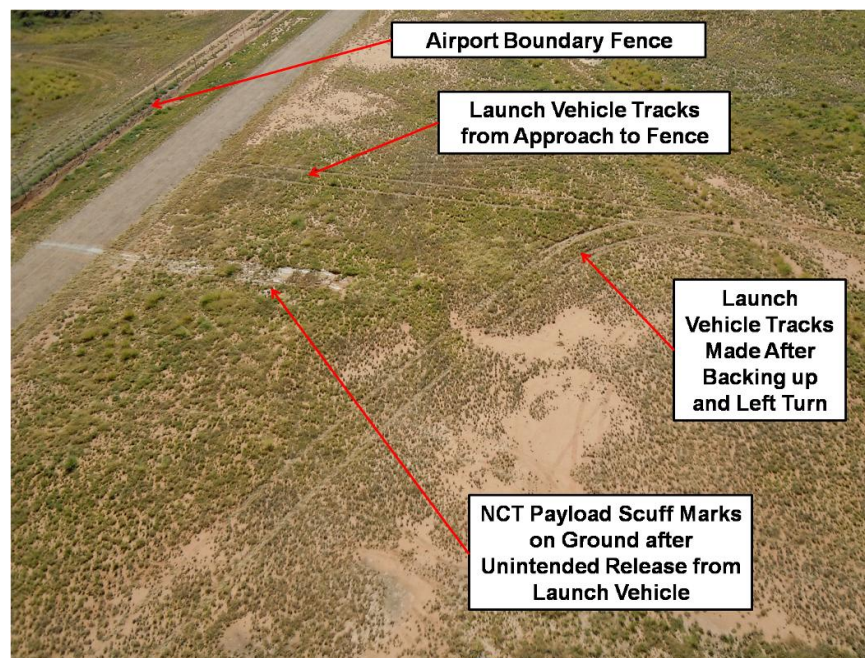


Figure 23. Location of Inadvertent Payload Release From Launch Vehicle

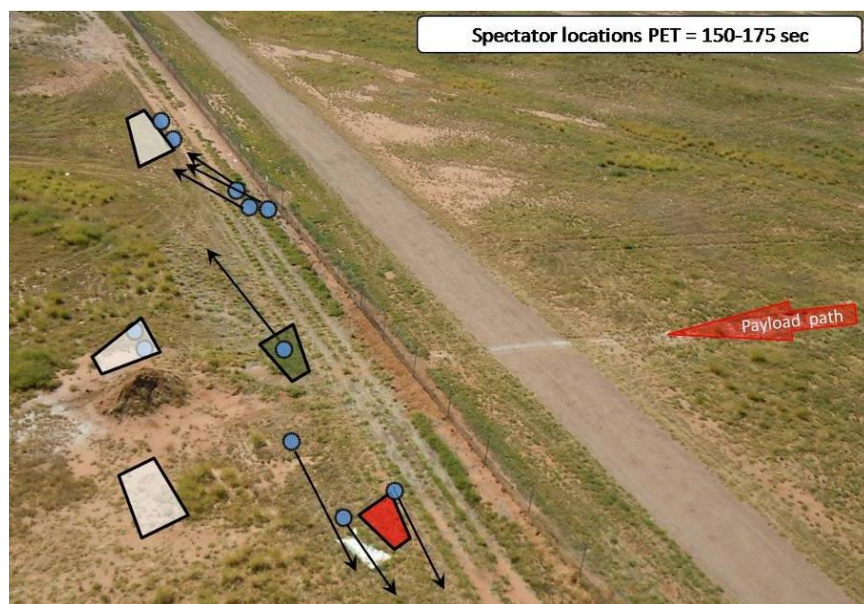


Figure 24. Spectator Location at PET 150-175 Seconds



Figure 25. Spectators Seen Running at PET 171 Seconds

**Key Event 47:** At PET=177 s the dragging payload hit a spectator's vehicle. At approximately the same time, the abort command was sent, releasing the balloon from the top of the parachute. After the balloon was separated from the parachute, the payload came to rest. Spectator locations at the time of impact and property damage are shown in Figures 26 and 27.



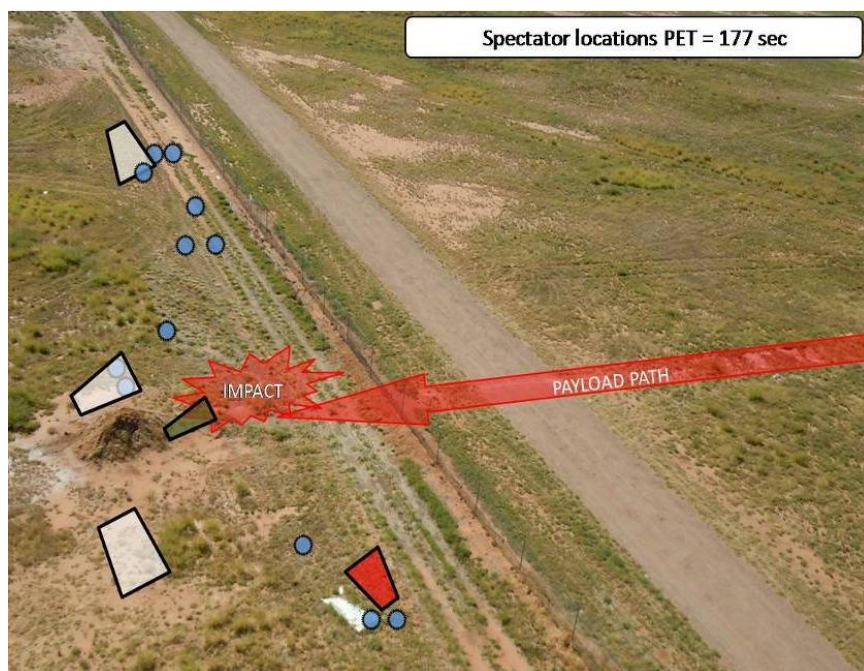


Figure 26. Spectator Location at PET 177 Seconds



Figure 27. Damaged Vehicles and Airport Fence

**Key Event 49:** The parachute and flight train were fully on the ground by **PET=199 sec**. The balloon came to rest on the ground some time later about  $\frac{1}{4}$  miles downwind in a field outside the airport indicated in Figure 28.



Figure 28. Balloon Landing Location

Immediately after the payload came to rest, spectators checked on the health of each other and all were found to be uninjured. The spectator that was on top of the impacted vehicle saw the danger and ran to protect himself as shown in Figure 29.

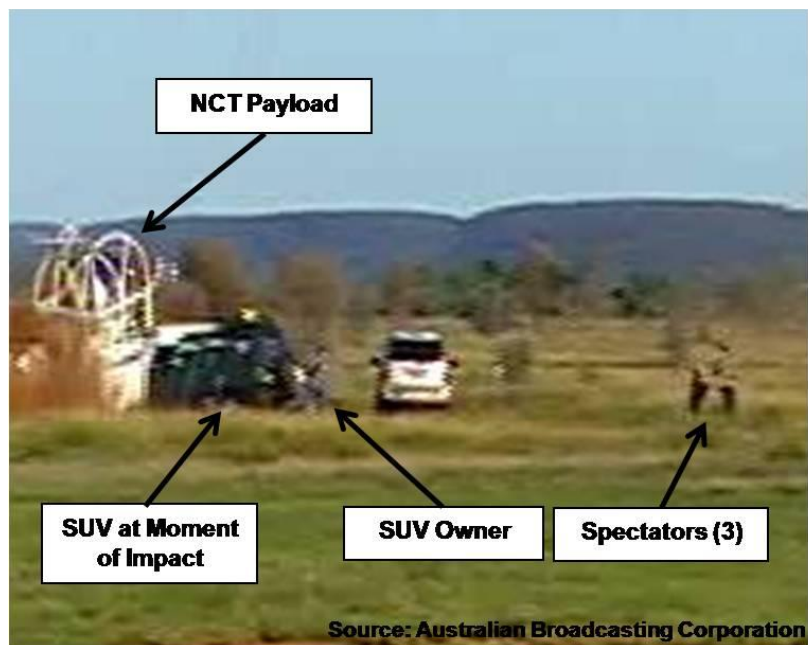


Figure 29. SUV Owner Running Just Before the SUV Was Impacted



The vehicle near the impacted vehicle had two spectators inside. This vehicle suffered cosmetic damage. Within 30 seconds after the event, spectators and camera crew had approached the damaged payload shown in Figure 30.



**Figure 30. Camera Crew and Spectators After the Mishap**

## **2.4 Emergency Response and Extent of Injury**

Realizing that a vehicle was hit and spectators were involved, the campaign manager did attempt to call emergency response personnel, but became confused between the United States “911” emergency number and the Australian “0” emergency number, and was unable to make the call. However, airport emergency response personnel did respond to the mishap scene in a timely manner owing to notification from the airport tower. Despite the fact that a private vehicle was hit and the general public outside the airport fence were observed running from the location at the time of the mishap, there were no injuries.

## **2.5 Events Occurring After the Mishap**

Right after the mishap, the CM initiated the CSBF mishap response requirements, notifying the CSBF Site Manager (Palestine, TX) and the BPO. Team members were assigned to various activities including gathering information, photographing the site, taking witness statements, and impounding flight and other appropriate data. CSBF personnel and NCT personnel began recovering the damaged payload and balloon flight train wreckage. NCT personnel set aside parts of the payload gondola to later be taken to a scrap yard for recycling.

The MIB chairman dispatched the board's field investigator to Alice Springs, Australia, ahead of the rest of the board, to start impounding evidence and collecting pictures, statements, and other vital information for the board process. Upon arrival to Alice Springs, the MIB field investigator learned that parts of the payload gondola were taken to the local scrap yard and demanded that such evidence be retrieved and impounded. BPO and CSBF management provided all other information gathered by the NCT and CSBF balloon teams. All balloon launch hardware, records, video recordings, and photographs were immediately impounded according to NPR requirements.

Because of the actions of the CSBF personnel in the recovery and removal of the wreckage from the mishap site to a holding location within the area, the physical evidence had to be declared as contaminated by the field investigator.

The NASA MIB was officially established on May 12, 2010.

### **3.0 Investigation**

#### **3.1 Approach**

The MIB visited the mishap site in Alice Springs, Australia, identified and interviewed witnesses, analyzed events and conditions, and inspected and tested the crane launch head device to determine its operational conditions. These activities helped to identify the proximate, intermediate, and root causes of the mishap. Each element of the investigation is further described in the following sections.

#### **3.2 Mishap Investigation Chronology**

The mishap was originally classified as a High Visibility, Close Call Mishap. Commissioned on May 12, 2010, the MIB collected information gathered by WFF BPO and the CSBF prior to May 12, 2010. The MIB's first visit to the mishap site occurred on May 8, 2010 by the MIB field investigator. The remainder of the board arrived at the mishap site on May 13, 2010.

The MIB kick-off meeting was held on May 13, 2010 at the Alice Springs Airport Conference Center in Alice Springs Australia (Figure 31). The NSC's Mishap Investigation Support Office (MISO) representative provided a mishap investigation process briefing. The Field Investigator briefed the board on safety in the "Australian Outback" and also provided the MIB with a status of the initial investigation efforts to date. The MIB chair assigned tasks to the MIB members. Initial pictures and documentation of the mishap area were reviewed by the MIB. Then the incident details were reviewed and site visits to the NASA Balloon Facility and mishap site were conducted.



**Figure 31. Alice Springs Airport, Alice Springs, Australia**

The MIB conducted three performance tests on the launch crane head and the payload release system at Alice Springs. Tests were performed to determine (1) performance characteristics of an unloaded launch release mechanism, (2) if a load placed on the pear ring would keep the payload from being released and (3) performance characteristics of the launch release system when loads were introduced through the truck plate.

After performing the review of witness statements and the CSBF Balloon documentation, an initial interview list was developed. Interviews of the CSBF personnel, payload personnel and members of the public watching the balloon launch attempt were scheduled and conducted.

Most members of the MIB departed back to GSFC to start board deliberations on May 15, 2010. The MIB co-chair remained at Alice Springs to complete onsite interviews and additional photography of evidence and mishap site mapping. He departed on May 20, 2010 to GSFC to rejoin the rest of the MIB.

A timeline of the key events leading up to the mishap was initially constructed, identifying all of the events related to the mishap, along with the dates/times that were known. The timeline of the mishap remained a working document, continually being updated as more data were received.

Due to unavailability of the Site Deputy Manager during the site visit to Alice Springs, a telephone interview was scheduled and accomplished at a later date. During the course of the investigation, additional BPO documentation was requested, and the interview list was expanded to include BPO and WFF Safety Management. A follow up interview with the LD was also accomplished.

### 3.3 Data Collection and Development

#### 3.3.1 Evidence, Interviews and Documentation

During the course of the investigation into the Nuclear Compton Telescope Balloon Launch Mishap, the MIB collected data and reviewed 18 witness statements that were taken by CSBF management prior to the MIB's arrival in Alice Springs. The MIB photographed evidence at the mishap site and obtained aerial photographic records of the mishap site. Photographs of the broken safety restraint cables are shown in Figures 32 and 33. The MIB conducted a total of 21 witness interviews. In addition, the MIB reviewed balloon launch operation procedures, equipment certifications, past balloon anomaly reports, equipment drawings, personnel certification training records, range and ground safety requirements, video and photographic evidence, and physical evidence. The MIB also performed strength testing on safety restraint cables that were manufactured as test samples for the board.

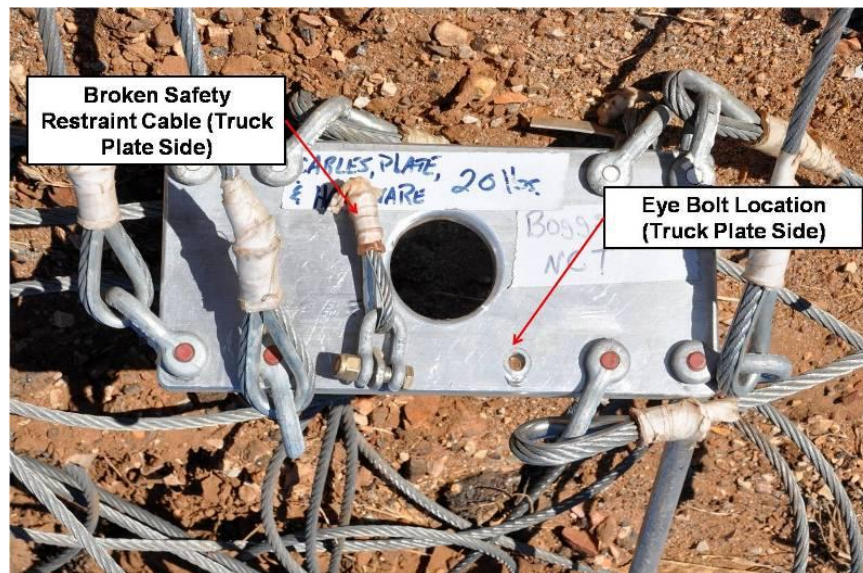
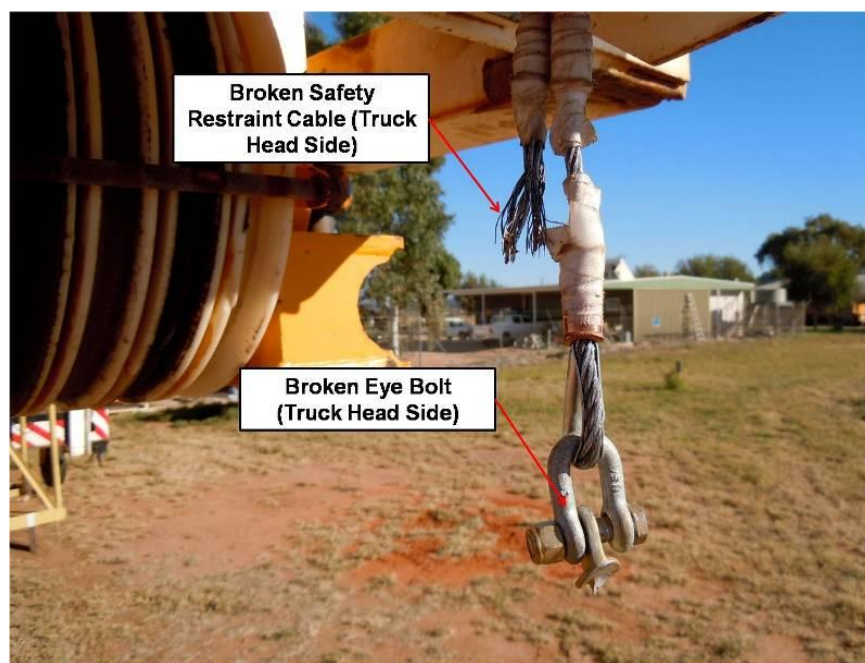


Figure 32. Truck Plate as Photographed at the at Mishap Site





**Figure 33. Broken Safety Restraint Cables on Launch Vehicle**

### 3.3.2 Type of Data Gathered

#### 3.3.2.1 List of Documents

The MIB reviewed documentation in the process of the investigation, including BPO Program Procedures, CSBF Procedures, Statement of Work, NASA Audit Reports, NCT Launch Checklist, CSBF Contract Requirements and others. Table 1 provides the list of documents reviewed by the MIB.

**Table 1—List of Reviewed Documents**

Title	Date	Type	Author
820-PG-1060.2.1A	February 16, 2005	Balloon Program Management Review and Reporting for Programs and Projects	BPO
820-PG-1410.2.1	February 16, 2005	BPO Configuration Management Procedure	BPO
820-PG-5100.1.1B	February 16, 2005	Management of the National Scientific Balloon Support Contract	BPO
820-PG-7120.1.1B	February 16, 2005	Management of the NASA Scientific Balloon Program	BPO
820-PG-7120.1.2C	February 16, 2005	Management of the NASA Balloon Flight Operations	BPO
820-PG-7120.1.3B	February 16, 2005	Management of Balloon Program Development Projects	BPO
820-PG-7120.1.4B	February 16, 2005	Management of the Balloon Program's Safety Implementation	BPO
820-PG-8621.1.1B	February 16, 2005	Investigation and Reporting Procedures for Balloon Program Mishaps, Failures, and Anomalies	BPO
820-CMPP-1002	February 16, 2005	NCT Mission Project Plan	CSBF
800-PG-1060.2.1F	September 8, 2008	Suborbital and Special Orbital Projects Directorate Review	Code 800/Directorate
800-PG-8715.0.4A	January 25, 2005	Certification Procedures for Operations Safety	Code 803/Safety Office

Title	Date	Type	Author
		Supervisors at Wallops Flight Facility (WFF)	
800-PG-8715.1.1	June 23, 2004	Unmanned Roadblocks for Hazardous Operations	Code 803/Safety Office
800-PG-8715.0.3	November 29, 2005	Viewing Locations for Personnel Not Essential to Launch Operations	Code 803/Safety Office
803-PG-8715.1.1E	August 20, 2008	Range Safety Operations Process	Code 803/Safety Office
803-PG-8715.1.13E	August 20, 2008	Ground Safety Process	Code 803/Safety Office
803-PG-8715.1.4D	August 20, 2008	Range Safety Project Planning Process	Code 803/Safety Office
803-PG-8715.1.14D	August 20, 2008	Safety Review Process	Code 803/Safety Office
CSBF Memo		NCT Mishap Quick Look Report	CSBF-Campaign Manager
OF-695-21-P-B		CSBF Mishap Procedures	CSBF-Campaign Manager
OF-610-00-P-B		CSBF Ground Safety Plan	CSBF-Campaign Manager
EL-500-00-F		CSBF NCT Flight Application	CSBF-Campaign Manager
EL-500-00-F-C		NCT Waiver of Claims	CSBF-Campaign Manager
OM-100-10-C		Launch Equipment Configuration & Certification	CSBF-Campaign Manager
OF-300-00-D		Flight Requirements	CSBF-Campaign Manager
OF-317-01-D-A		Gondola Certification	CSBF-Campaign Manager
OF-314-00-F		Pre-Flight Minimum Success Criteria	CSBF-Campaign Manager
OF-310-00-P-B		CSBF Flight Plan	CSBF-Campaign Manager
UNSW Memo		UNSW ASP-BLS Security Procedures	UNSW
C1000-09		Weight Sheet	CSBF-OPS
OF-322-00-M-A		Flight Data Summary	CSBF-OPS
OF-324-00-D-C		Inflation Computation	CSBF-OPS
OF-322-10-C-B		Launch Director Checklist	CSBF-OPS
OF-329-00-D		Balloon Condition Flt Line Rpt	CSBF-OPS
CSBF Memo		Helium Residual	CSBF-OPS
OF-306-00-D-A		Recovery Form	CSBF-OPS
NCT Memo		Recovery Instructions	CSBF-OPS
CSBF Memo		Post Flight Gauges & Scales	CSBF-OPS
OF-330-00-D-A		Balloon QC Info Sheet	CSBF-OPS
OF-328-00-C-A		Collar Flight Record	CSBF-OPS
OF-318-00-D		Rigging Job Assignments	CSBF-OPS
EC-500-02-P-D		Collar Electronics Certification	CSBF-Electronics
EC-700-05/04-F-B		Electronic Compatibility Checklist	CSBF-Electronics
NPR 8615.3	April 17, 2009	General Safety Program Requirements	HQ-OSMA
NPR 8615.5	July 8, 2005	NASA Range Safety Program	HQ-OSMA
NPR 8621.1B	May 23, 2006	NASA Procedural Requirements for Mishap and Close	HQ-OSMA

Title	Date	Type	Author
		Call Reporting, Investigating, and Recordkeeping	
NASA Std. 8719.9	May 9, 2002	Standard for Lifting Devices and Equipment	HQ-OSMA
RSM 2002-Rev B	July 14, 2008	Range Safety Manual for Goddard Space Flight Center (GSFC) Wallops Flight Facility (WFF)	WFF-OSMA
EC-100-01-F-B		CIP (Consolidated Instrument Package) Pack Record	CSBF-Electronics
EC-100-03-P-B		CIP Receiver	CSBF-Electronics
EC-100-02-P-B		CIP Command Demodulator	CSBF-Electronics
EC-100-04-P-B		CIP VCO Calibration	CSBF-Electronics
Cal. Printout		MKS (Baratron) Calibration	CSBF-Electronics
EC-100-05-P-B		CIP Environmental Record	CSBF-Electronics
EC-500-03-P-B		ATC Transponder Check	CSBF-Electronics
EC-700-12-C-A		CIP GAPR Flt Line Checklist	CSBF-Electronics
EC-800-02-F-B		GSE Tape Recording (Setup)	CSBF-Electronics
EC-300-11-P-D		RFU (Remote Firing Unit) Calibration	CSBF-Electronics
EC-300-04-P-E		UTP (Universal Termination Package) Battery Procedure	CSBF-Electronics
EC-700-13-C-F		UTP/RFU Preflight Test	CSBF-Electronics
EC-300-12-P-B		UTP/RFU Environmental Record	CSBF-Electronics
Abort 23 GSE DATA		CD of GSE LOS Data	CSBF
UNSW/CASA Doc		UNSW-CASA Letter of Agreement	UNSW/CASA
Meteorology Davis Weather Station		Surface Weather Conditions	Meteorologist
Weather Documentation		Meteorology Flight Forecast	Meteorologist
Weather Documentation		Meteorology Climbout and Descent Vector Forecast	Meteorologist
Weather Documentation		Meteorology Abort 23 OBS Report	Meteorologist
Weather Documentation		Meteorology Radiosonde Data	Meteorologist
Weather Documentation		Meteorology PIBAL Runs (Data)	Meteorologist
Weather Documentation		Meteorology Weather Surface Charts	Meteorologist
Training Records		Launch Crew Training and Reclass Action	CSBF
Interviews		Notes From Interviews	MIB
Interviews		Original CSBF Witness Statements	CSBF
Weather Documentation		TIGRE Meteorology Records	CSBF
Weather Documentation		Weather Summaries From Previous Alice Springs Launches	CSBF-Meteorologist
WFF Safety		April 2001 Flight Safety Analysis	BPO
GFSC/WFF Report		517N Report	BPO
GFSC/WFF Report		533N MIB Report	BPO
Audit Report		Safety Audit Reports	WFF Safety
RFP NAS5-03003	January 9, 2003	Balloon Program and National Scientific Balloon Facilities Contract – Safety and Health Plan	Physical Science Laboratory, New Mexico

Title	Date	Type	Author
			State University
LTM 1100/2 Liebherr		Crane Operations Manual	Liebherr Crane
S-2000-231-00012	August 8, 2000	IRIS Report, Close Call	GSFC
S-2000-246-00001	September 2, 2000	IRIS Report, Type A	WFF
S-2001-177-00013	June 26, 2001	IRIS Report, Incident	GSFC
S-2001-263-00009	September 20, 2001	IRIS Report, Incident	GSFC
S-2001-267-00009	September 24, 2001	IRIS Report, Close Call	GSFC
S-2005-206-00003	July 24, 2005	IRIS Report, Type C	WFF
S-2006-269-00001	September 25, 2006	IRIS Report, Close Call	WFF
S-2007-058-00015	February 22, 2007	IRIS Report, Close Call	WFF

### 3.3.2.2 List of Tests

The MIB accomplished four tests in the process of the investigation. The purpose of these tests was to determine the performance characteristics of the launch release mechanism under various loading conditions. The release mechanism, which was still attached to the launch crane, was impounded at the time of the mishap. The first field test was a no-load functional test of the launch release mechanism. The subsequent tests were performed under various loading conditions. Table 2 lists the tests performed.

**Table 2—List of Tests Performed**

Name of Test	Place Performed	Purpose
Field Test 1	Alice Springs	No-load lanyard pull test
Field Test 2	Alice Springs	Pull force required to release launch restraint pin under direct load
Field Test 3	Alice Springs	Pull force required to release launch restraint pin under simulated balloon load
Field Test 4	GSFC/WFF	Determine ultimate strength of safety restraint cables

## 3.4 Data Analysis

The MIB used the NASA Root Cause Analysis process to analyze the mishap. To support or rule out potential causal factors, tests and analyses were conducted. A summary of the test results is provided below. Test and analysis details are provided in Appendix C.

### Summary of Test and Analysis Results

**Launch Attempt**—(1) At the time of the launch attempt, the balloon was ahead of the launch vehicle. (2) The combined loads from the helium and the wind caused forces on the launch release pin in excess of 1000 lb. (3) The forces on the release pin resulted in release lanyard pull forces that exceeded reasonable human capabilities.

**Inadvertent Release**—(1) Tests show that the safety restraint cables have a break strength near 8000 lb. (2) Analysis shows that during the straight backing maneuver, rupture loads were not exceeded on the safety restraint cables. (3) After the left turn (event 43 in Table 3 in Section 3.5) the load was not

equally shared by the cables. (4) The load on a single cable exceeded its ultimate strength capability.

### 3.4.1 Test Results and Related Data

Due to the nature of the mishap involving the inadvertent release of the payload, inspections and field tests were deemed to be of immediate importance after the MIB team arrival in the field. It was confirmed that the launch head and crane had been generally preserved in the launch configuration. One exception was that the crane boom had been lowered in order to promote easier transportation. It should be noted that the boom height is constrained for the flight by adjustable restraint chains on the crane. These restraint chains were left in the launch configuration so that the boom height was easily reproducible during Field Test 3.

#### 3.4.1.1 Field Test 1

**Background**—The launch release mechanism was impounded immediately following the mishap. It remained attached to the launch crane and was preserved in the condition that existed after the inadvertent release of the NCT payload. After visually inspecting the hardware involved in the mishap at the mishap site, the MIB defined a series of tests to determine the performance characteristics of the launch release mechanism under various loading conditions. The first test was a functional operation test of the unloaded launch release mechanism.

**Summary of Test**—With no shear load on the restraint pin, an operator pulled on the release cable lanyard.

**Significance of Test**—It was first necessary to determine if the release mechanism would function properly under a no-load condition to determine if there were any mechanical or configuration-dependent conditions that may have prevented proper operation of the release mechanism.

**Test Conclusions**—The release mechanism functioned nominally when operated in the no-load condition.

#### 3.4.1.2 Field Test 2

**Background**—Evidence indicated that there was an attempt to pull the lanyard cable that retracts the release pin during the launch attempt, but the lanyard did not release the pin as expected. The test was designed to determine the approximate lanyard force required to release the pin under several conditions. Since the release pin can be loaded through a ring via the safety restraint cables, a variety of loads was applied to a flight-identical pear ring using suspended loads. The test configuration is shown in Figure 34.

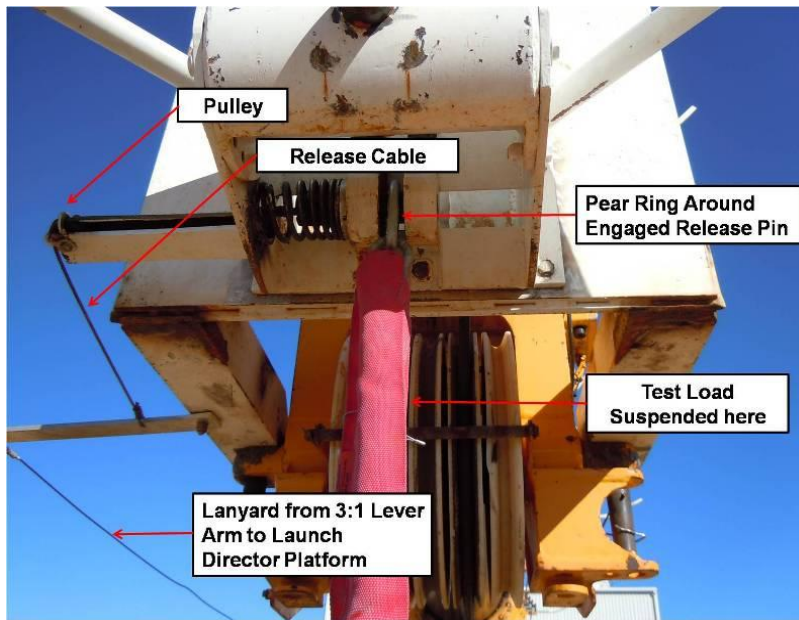


Figure 34. Field Test 1 Configuration

**Summary of Test**—A simple test was performed aimed at discovering the approximate forces required to pull the lanyard cable and retract the safety restraint cable release pin. The pear ring hanging from the release pin was subjected to a range of loading from zero to 1400 lb in order to determine the relationship between the pin loading and the load required to pull the release lanyard. The resulting lanyard forces ranged from approximately 50 lb at no load to 300 lb at 1400 lb load and are shown in Figure 35. The full test report is contained in Appendix C.

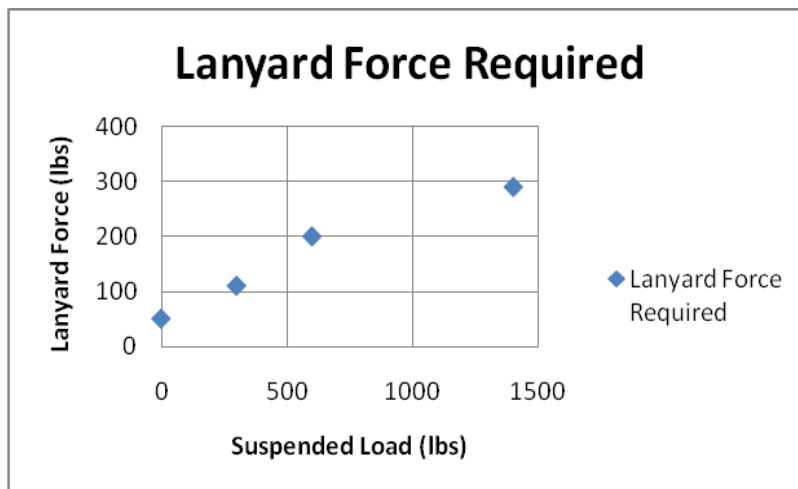


Figure 35. Lanyard Pull Force vs. Pear Ring Load

**Significance of the Test**—During the launch process, the LD is required to release the truck plate from the launch pin via the release lanyard. The required lanyard pull force increases with increase pin

loading. Resisting forces are created through friction with the pear ring and with the pillow block. The test is intended to determine the relationship of pear ring loading to the required lanyard pulling force.

**Test Conclusions**—The results of this test were generally as expected, showing an increase of the required lanyard pull force with increasing load on the pear ring. The pull force without any pear ring load is about 50 lb (an intentional design feature achieved with a pre-load spring). Human factors research indicates that the pull force would become difficult for the average adult male at about 100 lb, which is reached between 200 and 350 pounds of suspended weight (There is a 3:1 mechanical advantage between the release lanyard and the launch restraint pin).

### 3.4.1.2 Field Test 3

**Background**—Evidence indicated that there was an attempt to pull the lanyard cable that retracts the release pin during the launch attempt, but the lanyard did not release the pin as expected. This test was designed to determine the approximate lanyard force required to release the pin under loaded conditions. For this test, the balloon loads were simulated by applying loads with a crane through a cable harness and then through the truck plate. The configuration is shown in Figure 36.



**Figure 36. Field Test 2 Configuration**

**Summary of Test**—A simple set of tests was performed aimed at discovering the approximate forces required to pull the lanyard cable and retract the restraint cable release pin as a result of applied loads to the truck plate. The purpose of the test was to determine if loads applied to the truck plate (translated into loads on the pear ring and subsequently the restraint cable pin) through the flight train during launch operations would be sufficient to make release difficult for personnel. The truck plate was loaded in several representative ways to simulate potential launch loads. The applied test loads were limited in magnitude for two reasons: (1) To keep the crane and fitting loads well below the equipment

ratings for safety, and (2) To keep the required lanyard loads small enough for two people to be able to actuate the release. Loads of approximately 1000 and 2000 lb were applied at forward and side angles of approximately 8 degrees and 15 degrees, including combinations of forward and side angles. The resulting lanyard forces ranged from approximately 100 lb at 1000 lb applied with zero forward and side angles (pulling straight up) to approximately 215 lb at 2000 lb with 15-degree forward angle and 0-degree side angle. Sample data are shown in Figure 37. The full test report is contained in Appendix C-1.

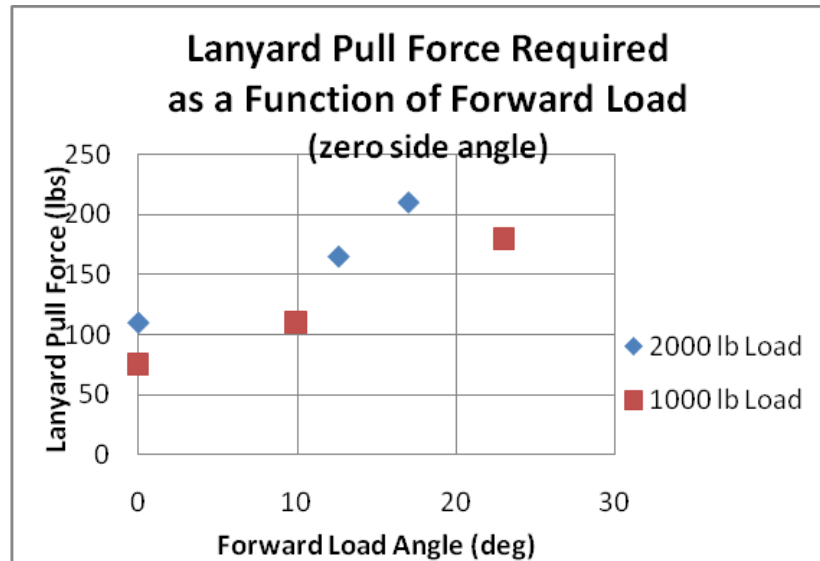


Figure 37. Lanyard Pull Force vs. Truck Plate Loading

**Significance of the Test**—During the launch process, the LD is required to release the truck plate from the launch pin via the release lanyard. The required lanyard pull force increases with increased pin loading. Resisting forces are created through friction with the pear ring and with the pillow block. The test was intended to determine the relationship of truck plate loading to the required lanyard pulling force.

**Test Conclusions**—The results of this test were generally as anticipated. Increasing loads through the truck plate increased the lanyard pull force. Increasing forward load angle increased the lanyard pull force. Increasing side angle increased the lanyard force only mildly, except for some combined load conditions where the lanyard force appeared to decrease.

Considering that the designed free lift (net lifting force on the launch pin) is about 985 lb, the lanyard force required for a balloon directly overhead would seem reasonable at about 80 pounds (in a no-wind condition). However, the tests indicate that with relatively small forward angles of 10 to 15 degrees (balloon ahead of the launch crane), the lanyard force could rise to 125 to 150 pounds. Adding loads created by the wind on the balloon could easily result in required lanyard pull forces well in excess of 200 pounds.



### 3.4.1.3 Field Test 4

**Background**—During the attempted launch operation and subsequent mitigation actions, the safety restraint cables ruptured, allowing the payload to disengage from the launch head and be pulled free by the balloon.

The cable ultimate strength for the 1/4" 7x19 aircraft cable is reported to be 7000 lb by document OM-200-18-D. The complete test report is contained in Appendix C-1.

**Summary of Test**—A simple destructive pull test was performed at WFF on safety restraint cable sets similar to those used for the NCT launch attempt to determine the actual break strength of the safety restraint cables. The cable sets were supplied by the CSBF. Two break tests were performed showing the breaking strength to be 8,000 (+/- 20) lb. Figure 38 shows the test setup.



**Figure 38: Safety Restraint Cable Strength Test Configuration**

**Significance of the Test**—Forces in the range of 7,000 pounds (cable specification) to 8,000 pounds (pull test of representative cables) must have existed in order to rupture the restraint cables.

**Test Conclusions**—The test confirms the ultimate cable strength used by the CSBF.

### 3.4.2 Engineering Analysis

#### 3.4.2.1 Analysis of Applied Forces by the Balloon and Flight Train System

Static and dynamic simulations were conducted to estimate the forces present in the balloon and flight train elements during the Nuclear Compton Telescope inadvertent payload release and to predict the ground track of the balloon. These analyses were important to help support or refute conclusions drawn

from observations and evidence. The analyses included approximations of the balloon and flight train distributed weights, the drag forces produced by the relative wind on all elements, and the lift forces generated by the buoyant forces on the contained helium. While these analyses were conducted to understand the loading conditions during the entire timeline, the focus was on the following four most significant loading events: launch attempt, arrival at the Airport fence, the backing maneuver, and inadvertent payload release.

The system of structural elements and forces produces a complex catenary (the catenary is the characteristic curved shape typically produced by the combination of weight and tension forces on a suspended cable-like structure). The geometry is well represented in Figure 39, which shows the system upon arrival at the Airport fence.



**Figure 39. Catenary When Launch Vehicle Arrives at Fence**

This catenary system was modeled using two different methods, a multi-element, equilibrium, steady-state “shooting method” and a dynamic, elastic model that solves the accelerations of a lumped mass and spring system. Wind profiles were modeled using actual PiBal data. The two models agree well for compared static conditions. The results of the static and dynamic assessments were correlated with photo and video evidence and show agreement with catenary photo comparisons. Results predict considerable forces at the truck plate during the four key events.

With regard to the accuracy of the analytical predictions, it should be noted that the launch vehicle position data from GPS was limited to 1/5 Hertz frequency. There were no data providing the actual position of the balloon bubble (except for some video evidence early after spool release). Wind data

were limited to several altitudes at times prior to the event and after the event. In addition, the actual effective drag coefficients on each element of the system as a function of time are difficult to characterize. A complete discussion of the analysis is included in Appendix C-2.

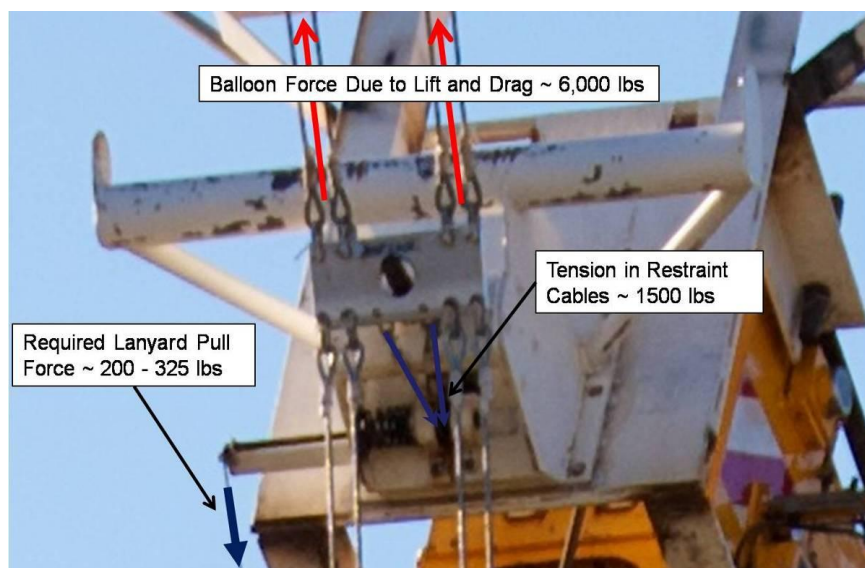
### **Summary of Analysis Results**

The estimated forces are consistent with the inability of the LD to actuate the release lanyard successfully during the launch attempts. In addition, the estimated forces are also consistent with the rupture of the restraint cables at the time of inadvertent payload release.

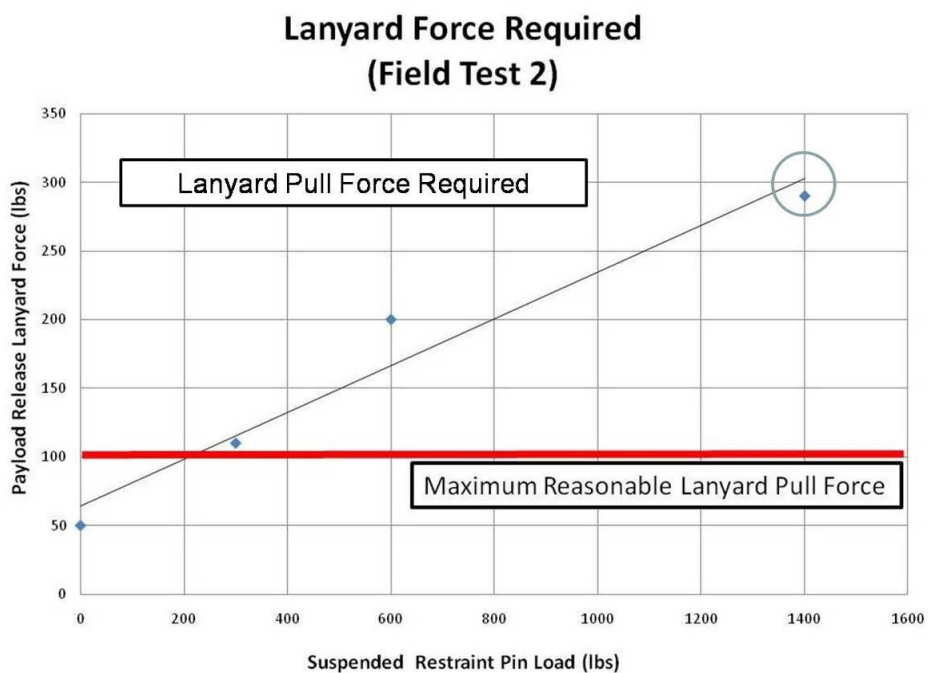
#### **3.4.2.1.1 Analysis Results at Time of Launch Attempt (PET=86 seconds)**

For the launch attempt analysis, the important result is to determine the pull force required on the release lanyard at the time of the launch attempt. Due to the shear forces applied to the release pin through the pear ring, the lanyard pull force is a function of the forces generated by the balloon and the relative position of the balloon to the launch vehicle. At the time of the attempted launch (attempted actuation of the retention pin release lanyard), the geometry of the balloon and flight train was somewhat different than it was at the time the launch vehicle arrived at the fence as depicted in Figure 39. From photographic evidence, the forward angle appears to be about 10 degrees (80 degrees from horizontal). At this angle, the load in the safety restraint cables after resolving the force along the launch head pin is reduced to about 60% of the load in the flight train (assuming no appreciable reduction due to friction). Both the static and dynamic analyses show a total flight train force introduced into the truck plate of about 6000 lb once the vehicle slowed for the launch attempt. The resulting total safety restraint cable force is then about 1500 lb, or 750 lb on each cable.

Using the data from Field Test 1, the resulting lanyard pull force would be predicted to be in excess of 300 lb (test data only covered up to 1400 lb suspended). Predicted loads on the launch mechanism and the resulting required lanyard pull force at the time of the launch attempt are shown in Figures 40 and 41.



**Figure 40. Forces on Launch System at Launch Attempt Created an Unviable Condition**



**Figure 41. Required Lanyard Pull Force at Time of Launch Attempt**

Using the dynamic analysis and assuming the attempted lanyard actuation was before the vehicle began to slow, the lanyard force would be estimated as low as 200 lb. Therefore it is estimated that at the time of the launch attempts, the predicted lanyard pull force resulting from the balloon and flight train catenary was likely in the range of 200 to 300 lb. The required pull force during the launch

attempts was clearly well in excess of human capabilities. This is consistent with the inability of the LD to effect a successful release.

**Analysis Finding: The lanyard pull force at the time of attempted release exceeded reasonable human capability.**

#### **3.4.2.1.2 Analysis Results for Vehicle at Fence (PET=112 seconds) and During the Backing Maneuver (PET=118 to 148 seconds)**

The catenary Steady State Equilibrium analysis solution produced a good geometric fit with the photographic evidence as shown in Figure 42 when the launch vehicle was stopped at the Airport fence. The necessary forces at the truck plate to support the system weight and drag through the catenary were calculated to be approximately 9350 lb at approximately 38 degrees from horizontal. The associated horizontal drag force component was approximately 7300 lb.



**Figure 42. Static Catenary Assessment**

Those forces are reacted at the launch head pin (this is not the *release* pin). The launch head pin has an operation angle of approximately 25 degrees from the horizontal as determined from photographic evidence. Resolving these applied forces along the launch head pin gives a force along the pin direction of about 9200 lb. Considering the contribution of the payload weight on the bottom of the truck plate leaves a force of approximately 6300 lb transmitted directly to the restraint cable pair, pear ring and release pin. This compares to the specified ultimate load of the restraint cables of 7000 lb each, or 14,000 lb for the pair.

During the backing maneuver, the added relative wind speed on the balloon produced a further

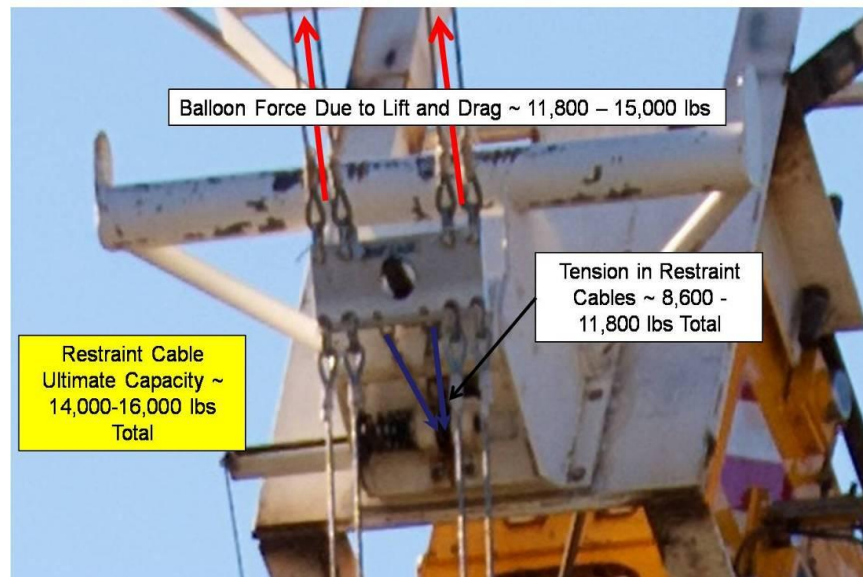
depressed catenary and increased forces at the launch head. Similar analysis yields total forces at the launch head from 11,800 to 15,000 lb and cable forces of 10,500 lb or more.

**Conclusions**—For the condition when the system was stopped at the fence and during the backing maneuver, it is reasonable to suspect that both safety restraint cables were sharing the load. This assumption is supported by photographic evidence. With approximately 14,000 (using the specification) to 16,000 (using the pull test results) pounds of strength to break available, it would be expected that the predicted applied cable loads while stopped at the fence and during the backing maneuver would not result in a failure condition. The loading condition during the backing maneuver is illustrated in Figure 43.

**Analysis Finding: Predicted loads in the safety restraint cables while the launch vehicle was at the fence would not have resulted in cable rupture.**

**Analysis Finding: Predicted loads in the safety restraint cables during the backing maneuver would not have resulted in cable rupture.**

**Analysis Finding: The safety restraint cables were used in a backing operation that the cables were not designed to perform. The implemented factor of safety was approximately 1.3, which is inadequate for this operation.**



**Figure 43. Forces on Launch System During Backing Maneuver  
Created Unsafe Operating Condition**

#### **3.4.2.1.3 Analysis Results for Vehicle at Time of Unintended Release (PET=171 seconds)**

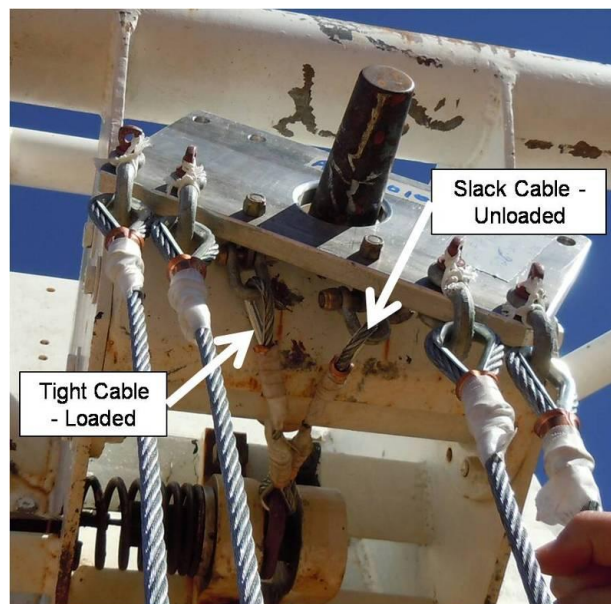
For the condition when the vehicle was turned left in an attempt to pull the system away from the



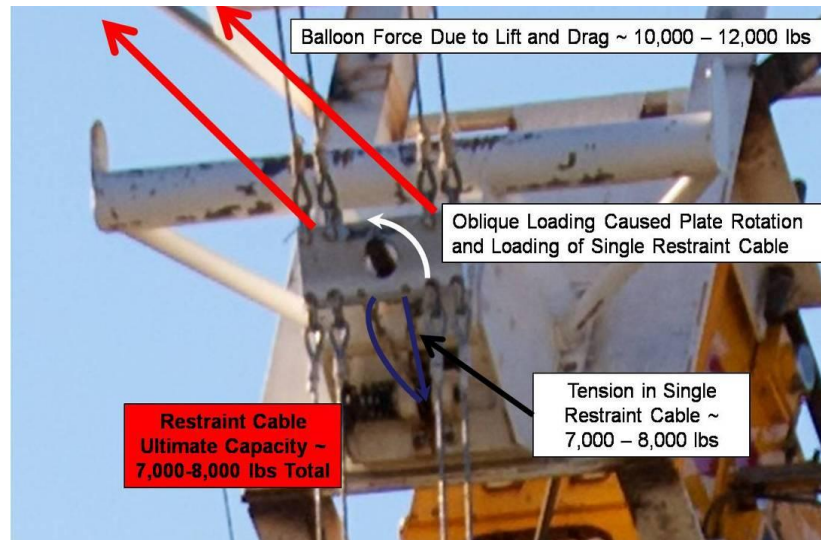
people, it is reasonable to suspect that the load was unevenly distributed between the cables due to the twisting action that is produced when the truck plate is loaded from the side. The MIB simulated the oblique loading condition on the truck plate during the site visit to Alice Springs in order to understand the behavior characteristics of the restraint cables. As seen in Figure 44, an oblique loading condition on the truck plate, such as the condition that existed at the time of restraint cable rupture, causes one restraint cable to be un-loaded. It is in a side-loaded condition that the cable assemblies ruptured.

Loads analysis predicts that the total load at the launch head produced by the balloon system was on the order of 10,000 to 12,000 lb at the time of release. This translates into about 7000 to 8000 lb in the restraint cables, which is at the rupture limit of the cables. Additionally, any pendulous motions would have the potential of adding to the maximum forces seen by the restraint cables. If most of the 8000 lb were applied to one cable, rupture would be expected in first one cable, then the other. The predicted load conditions at the time of restraint cable rupture are shown in Figure 45. Any other conditions caused by the twisting truck plate that produced combined loads (e.g., bending and tension) on the eyebolt elements would only have exacerbated the problem.

During the left turn maneuver of the launch crane, one restraint cable became off-loaded. The remaining restraint cable reacted the loads from the wind-driven balloon, which exceeded the cable's ultimate strength capability. One restraint cable ruptured, causing the unloaded cable to pick up the load. The second cable assembly also broke due to the loading condition. The load conditions and predictions of hardware behavior are consistent with hardware evidence collected in the field at Alice Springs.



**Figure 44. Oblique Truck Plate Loading Off-Loads One Restraint Cable**



**Figure 45. Forces on Launch System During Turning Maneuver Resulted in Cable Rupture (Note that there was no face-on photograph of the hardware at the time of rupture.)**

**Analysis Finding:** Analysis of the balloon, flight train, and crane system predicts that the loads on the safety restraint cable assemblies exceeded the load carrying capability of the cable assembly at the time of the inadvertent payload release due to the magnitude and relative geometry of the loads on the flight train.

#### **3.4.2.1.4 Analysis Results for Launch Head Forces Required for a Hypothetical Case of No Collar Release**

An analysis was performed to determine the likely level of forces at the crane launch head mechanism for a condition where the reefing collar had not been released prior to release from the launch pin in order to determine if collar release timing played a role in the mishap.

The drag areas were determined based on photographic evidence of the balloon just prior to the collar release. In this condition, the drag area is somewhat less than that observed after the collar release. The new drag area was used with the same effective drag coefficient that was shown to cause analysis agreement with both the overall catenary shape and terminal angle at the launch head.

Application of the same analytical technique yielded an ultimate force at the launch head of approximately 8000 lb with the collar compared to 10,000 lb without the collar. Resolving the 8000 lb into the safety restraint cables leads to a total cable pair force of 5500 to 6500 lb. This compares to the 7000 to 8000 lb predicted for the actual launch attempt condition.

## **Conclusions**

While maintaining the collar until after pin release would have reduced the cable load on the safety restraint cables, perhaps enough to prevent rupture, the load would have still been well in excess of a safe load for one cable. In addition, other real loading conditions, such as pendulous modes of the payload would have likely caused the restraint cable to be exposed to loads exceeding its capability. Further, it is unlikely that collar release would have been postponed until after the backing maneuver, given current standard operations implementation.

**Analysis Finding: Retaining the collar until release reduces the total loading in the launch head and improves the likelihood of successful lanyard pull in the event of non-optimal balloon position.**

**Analysis Finding: It cannot be concluded from the analysis that retention of the collar until after release would have prevented safety restraint cable rupture.**

#### **3.4.2.2 Analysis of Applied Forces by Pendulous Payload Dynamics**

During the launch process, when the launch vehicle is moving, the payload generally exhibits pendulous motion due to the inertia of the payload and the applied forces at the suspension point (truck plate) applied at the launch head pin. The forces generated on the truck plate due to the dynamics of the payload can then be translated into the safety restraint cables and thereby have an effect on the lanyard pulling force required for a successful release of the payload.

The forces of interest in this pendulum system are produced by two accelerations. One is from the acceleration of gravity, producing the weight component, and the other is from the acceleration due to the circular motion, producing the centrifugal force component.

For the launch conditions here, peak angular amplitudes were observed up to approximately 20 degrees, which could produce horizontal forces up to approximately 1400 lb.

### **Conclusions**

It is sufficient to say that pendulous motions have the potential for generating significant forces that add to the forces transmitted through the flight train and truck plate into the restraint cables. This can result in increased difficulties regarding the lanyard pull and increased likelihood of restraint cable rupture during the time of inadvertent release.

**Analysis Finding: Analysis shows that in the absence of any additional force, the pendulous motion of the gondola had the potential to produce significant forces in the restraint cable system, which may have added to the inability to effect payload release at the release attempt.**

**Analysis Finding: Analysis shows that in the absence of any additional force, the pendulous motion of the gondola had the potential to produce significant forces in the restraint cable system, which may have contributed to the forces causing restraint cable rupture.**

#### **3.4.2.3 Analysis Results for Hypothetical Case of No Loss of Traction at PET=62 sec**

During the process of maneuvering the launch vehicle for launch attempt the vehicle lost traction. This occurred at about 62 seconds. Because this caused a delay in the acceleration of the crane, an analysis was completed to determine if assuming good traction throughout would have likely improved the launch release situation.

The dynamic analysis tool was used to simulate the hypothetical case. As expected, assuming better traction improved the launch situation due to the increased average velocity of the launch vehicle. Significant improvement was achieved by maintaining traction and also taking a better path (more toward the South). For this condition, by 86 seconds, the estimated release lanyard force is less than 100 lb.

**Analysis Finding: It is unlikely that improved traction would have reduced the release lanyard pull force to acceptable levels, but analysis is inconclusive.**

**Analysis Finding: The combination of better traction and a better steering path for the launch vehicle would have likely increased the chances of a successful release.**

**Analysis Finding: Given the initial wide right turn and correcting left turn, in all cases the launch vehicle would have been outside the Category A hazard area by the time a launch could have been affected.**

#### **3.4.2.4 Analysis of Photo and Video Evidence and Correlation with Dynamic Analysis**

The MIB obtained six video recordings and approximately one thousand photographs of the NCT launch attempt. In order to help construct the timeline and analyze the events of the launch attempt, all six video sources were time-synchronized by identifying key and common features and landmarks. The MIB produced several composite video compilations of the entire timeline sequence. The catenary predictions from the dynamic simulation were then correlated with the same events as observed in both the video compilations and the photographic evidence. This correlation was excellent and demonstrated that the dynamic simulation accurately predicted the catenaries for the timeline events. (Figures 46 through 51) show the video evidence and positions of the balloon and launch vehicle for 6 key events.

Key Event 27 PET = 44 seconds  
Launch crane turns left after sweeping right turn

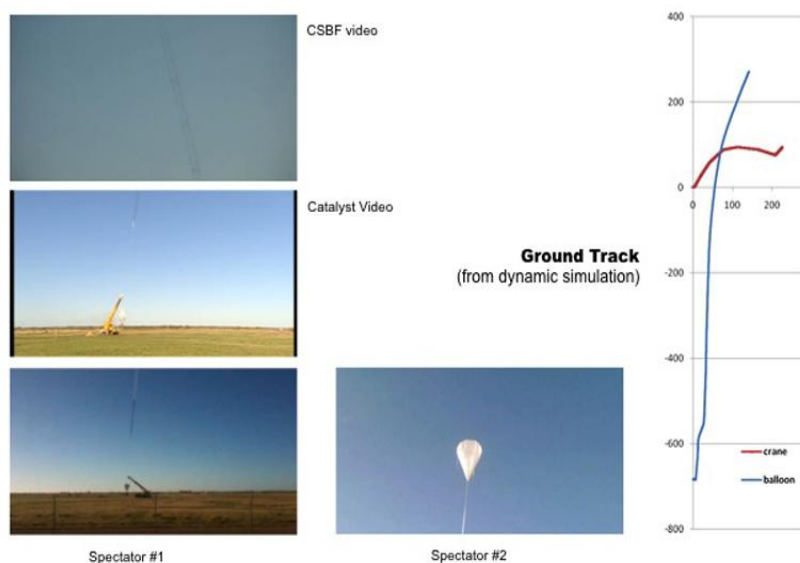


Figure 46. Video Evidence and Ground Tracks for Key Event 27

Key Event 30 PET = 62 seconds  
Launch crane slows down due to loss of traction

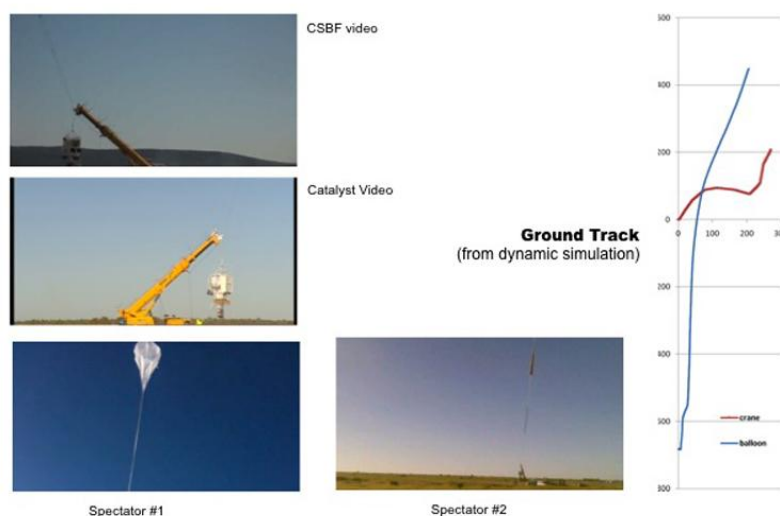


Figure 47: Video Evidence and Ground Tracks for Key Event 30

Key Event 34 PET = 86 seconds  
Launch crane slows down for launch attempt

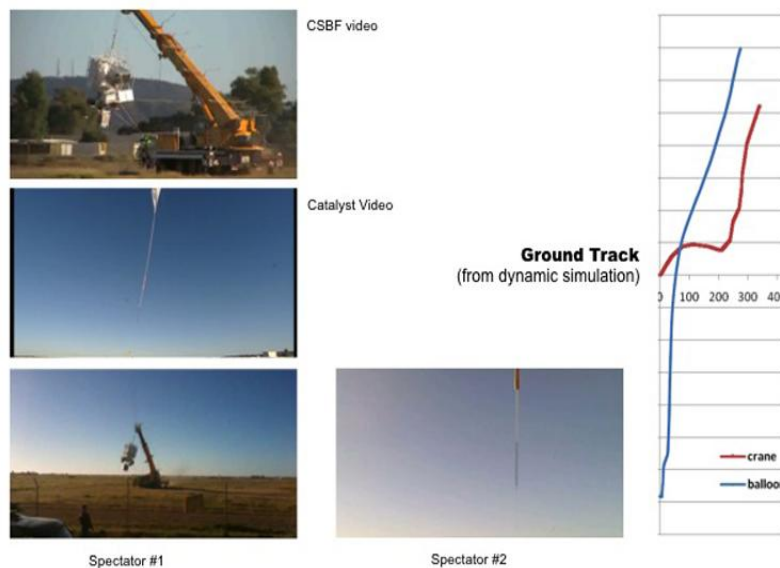


Figure 48. Video Evidence and Ground Tracks for Key Event 34

Key Event 39 PET = 105 seconds  
Launch crane stops at Airport perimeter fence

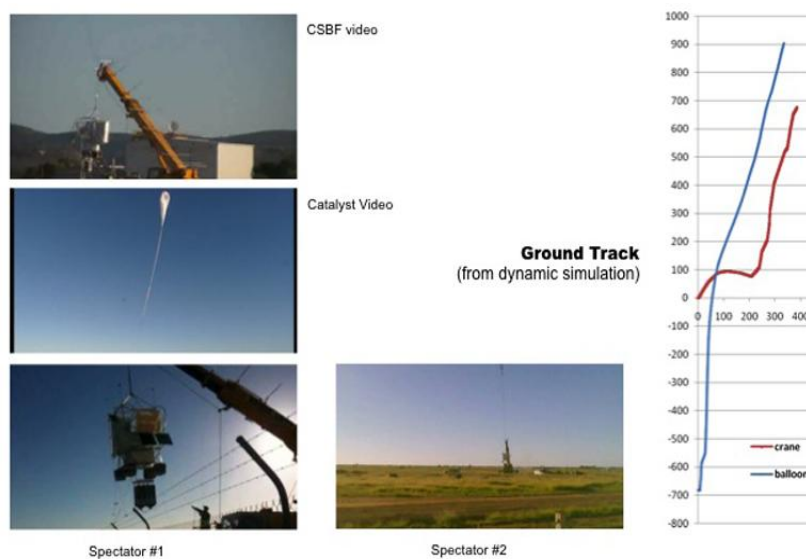


Figure 49. Video Evidence and Ground Tracks for Key Event 39



Key Event 43 PET = 150 seconds  
Launch crane starts left turn after backing up

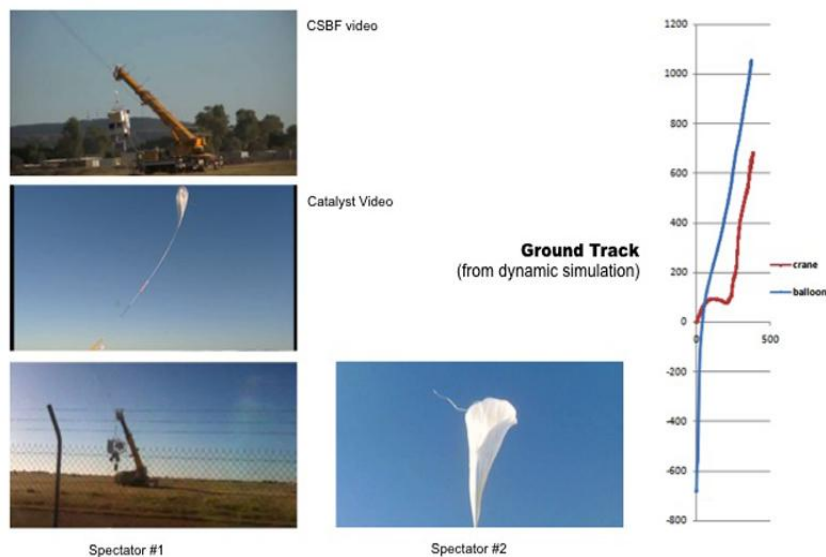


Figure 50. Video Evidence and Ground Tracks for Key Event 43

Key Event 45 PET = 171 seconds  
NCT payload inadvertently separates from launch  
crane

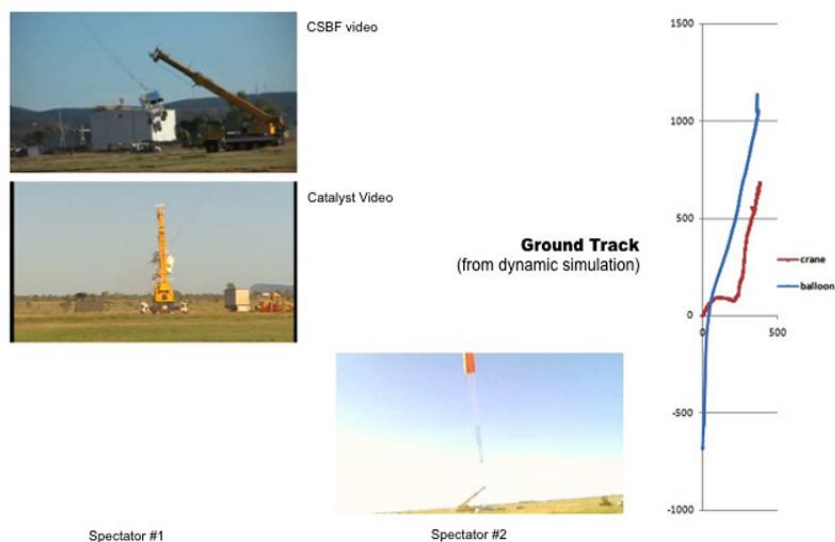


Figure 51. Video Evidence and Ground Tracks for Key Event 45

### **3.4.3 Safety Requirements Assessment**

The MIB conducted a Safety Requirements Assessment to determine areas where the applicable safety requirements were either overlooked (constituting non-compliance) or implemented poorly (constituting nonconformance with intent of the requirement). The MIB examined the following areas: Personnel Protection, Hazard Analyses, Ground Safety Plan, Hazardous Operations, Safety Oversight, Past Safety Audits, Crane Operations, Safety Independence, Operator Training, and Effectiveness of the Mishap response plan. The requirements documentation examined for compliances included, but were not limited to: NASA Policy Directives; NASA Procedural Requirements; NASA Standards; NASA Range Safety Manuals; GSFC/Wallops Procedural Requirements; Suborbital and Special Orbital Project Balloon Procedures and Guidelines; Program Office Procedures and Guidelines; WFF Safety Office Procedures and Guidelines; WFF Safety Office work instructions; and the CSBF Contract documentation.

These requirements were compared with the information gathered through review of GSFC/WFF and CSBF program documentation and records, witness statements, witness interviews, video documentation, and still photography.

The findings of the requirements assessment are provided in Appendix D. Matrices mapping the results of this assessment to the root cause and intermediate cause findings, along with listings of the referenced safety requirements and excerpts of referenced requirements, are located in Appendix D of this report. The results of this safety assessment were used as inputs to the Root Cause Analysis that is described in Section 3.6.

### **3.4.4 Human Error Assessment**

The Alice Springs balloon launch mishap was assessed for human events and conditions that may have caused or contributed to the incident. The purpose of this assessment was to generate recommendations that will reduce human error and/or mitigate the negative consequences of human actions.

This assessment was based on the evidence collected via interviews as well as documentation, photographic, and video evidence. It was determined that internal shaping factors such as human limitations of physical strength, division of attention, and mental workload capacity were contributors as well as external factors including deficiencies in information (availability, clarity, quality) and designation of tasks, design of equipment, enforcement of rules, regulations and policies, and conflict of goals. The highlighted human events are taken from the E&CFT and are categorized for the purpose of this assessment by action type (error of omission, error of commission, or failed or changed state) and error type (perception, interpretation, decision-making, or action execution or failure). Next, potential barriers and control methods are evaluated to determine why they either failed or did not exist. The recommendations generated are designed to prevent similar occurrences and are closely related to and mapped to the general findings of the report found in Section 1. The results of the Human Error Assessment can be found in Appendix D-3.

### 3.5 Timeline

While gathering data, the MIB developed and maintained a timeline of the events leading up to the mishap. This timeline initially started with the events immediately prior to the mishap. As the RCA progressed, the time line expanded further back in time to include events that were related to the intermediate causes and the proximate causes. The MIB time-synchronized all six video evidence recordings to help determine the PET of events following spool release. The detailed timeline is shown below in Table 3. Significant key events from this timeline are shown overlaid with the launch vehicle's GPS track in Figure 52.

**Table 3—Detailed Timeline**

Date	Time	PET	Name	Description
4/29/2010	02:18:00 AM		Event 1	PIBAL run accomplished by meteorologist.
4/29/2010	02:30:00 AM		Event 2	CSBF team reports to station at Alice Springs Australia to attempt NCT balloon launch
4/29/2010	02:59:00 AM		Event 3	Meteorologist runs another PIBAL.
4/29/2010	02:59:00 AM		Event 4	PIBAL readings indicate winds resulting in Launch Director determining a 110 degree balloon layout.
4/29/2010	03:00:00 AM		Event 5	NCT payload picked up and transported to launch vehicle.
4/29/2010	03:30:00 AM		Event 6	Launch vehicle and balloon train rolled out to flight line.
4/29/2010	03:32:00 AM		Event 7	PIBAL run accomplished.
4/29/2010	04:18:00 AM		Event 8	PIBAL run accomplished.
4/29/2010	04:48:00 AM		Event 9	PIBAL run accomplished
4/29/2010	05:18:00 AM		Event 10	PIBAL run accomplished and NOTAM updated to reflect a 1 hour delay
4/29/2010	05:54:00 AM		Event 11	Launch Director requests the balloon to be laid out for launch.
4/29/2010	05:54:00 AM		Event 12	PIBAL run accomplished
4/29/2010	06:30:00 AM		Event 13	PIBAL run accomplished
4/29/2010	06:43:00 AM		Event 14	PIBAL run accomplished.
4/29/2010	06:43:00 AM		Event 15	Inflation of the balloon started.
4/29/2010	06:43:00 AM		Event 16	Launch Director notices spectators in the downwind flight path and request their relocation.
4/29/2010	07:40:00 AM		Event 17	PIBAL run accomplished.
4/29/2010	07:40:00 AM		Event 18	PIBAL run indicated a wind shift to 121 degrees.
4/29/2010	07:50:00 AM		Event 19	Balloon inflation completed.
4/29/2010	07:50:00 AM		Event 20	Collar 1 and Collar 2 manned.
4/29/2010	07:50:00 AM		Event 21	Site manager requested ATC clearance to launch.
4/29/2010	08:02:00 AM		Event 22	Clearance received from ATC for launch.
4/29/2010	08:05:19 AM	0 sec.	Event 23	Spool released to launch balloon.
4/29/2010	08:05:29 AM	10 sec.	Event 24	Launch Director orders launch vehicle driver to drive forward making a sweeping right 90-degree turn.

Date	Time	PET	Name	Description
4/29/2010	08:05:56 AM	37 sec.	Event 25	Collar 1 called for collar release.
4/29/2010	08:05:58 AM	39 sec.	Event 26	Collar 2 called for collar release
4/29/2010	08:06:04 AM	45 sec.	Event 27	Launch vehicle comes to a stop.
4/29/2010	08:06:05 AM	46 sec.	Event 28	Voice confirmation of “collar off”
4/29/2010	08:06:06 AM	47 sec.	Event 29	Launch Director orders launch vehicle driver to turn left to align with balloon’s flight path
4/29/2010	08:06:21 AM	62 sec.	Event 30	Vehicle slows down due to loss of traction and then speeds up to catch the balloon.
4/29/2010	08:06:38 AM	79 sec.	Event 31	Launch vehicle breaches the Category A hazard area.
4/29/2010	08:06:45 AM	86 sec.	Event 32	Launch vehicle decelerates for launch attempt.
4/29/2010	08:06:46 AM	87 sec.	Event 33	Team member controlling the taglines to the payload loses hold of the payload restraint straps and the payload starts swinging wildly.
4/29/2010	08:06:46 AM	87 sec.	Event 34	First visible launch attempted by pulling on the release cable without effect.
4/29/2010	08:06:48 AM	89 sec.	Event 35	Second visible launch attempted by pulling on the release cable without effect.
4/29/2010	08:06:50 AM	91 sec.	Event 36	Launch vehicle comes to a stop.
4/29/2010	08:06:52 AM	93 sec.	Event 37	Launch Director orders launch vehicle driver to go forward to catch the balloon.
4/29/2010	08:06:53 AM	94 sec.	Event 38	Launch vehicle lost traction while accelerating.
4/29/2010	08:07:04 AM	105 sec.	Event 39	Launch vehicle stops at airport perimeter fence.
4/29/2010	08:07:04 AM	105 sec.	Event 40	Due to spectators being in the downwind path and close proximity Launch Director cannot order flight termination.
4/29/2010	08:07:17 AM	118 sec.	Event 41	Launch vehicle starts moving in reverse.
4/29/2010	08:07:47 AM	148 sec.	Event 42	Launch vehicle loses traction in soft dirt and cannot continue in reverse.
4/29/2010	08:07:49 AM	150 sec.	Event 43	Launch Director orders the launch vehicle driver to pull forward making a left 90-degree turn.
4/29/2010	08:08:10 AM	171 sec.	Event 44	Safety restraint cables snapped.
4/29/2010	08:08:10 AM	171 sec.	Event 45	Uncontrolled release of the Nuclear Compton Telescope payload resulting in the payload impacting the ground, then a privately owned vehicle and nearly causing injury or death to public spectators. (Undesired Outcome)
4/29/2010	08:08:10 AM	171 sec.	Event 46	Abort called.
4/29/2010	08:08:16 AM	177 sec.	Event 47	Payload impacted the POV
4/29/2010	08:08:19 AM	180 sec.	Event 48	Abort accomplished.
4/29/2010	08:08:38 AM	199 sec.	Event 49	Parachute and flight train come to rest on ground
4/29/2010	08:10:00 AM	281 sec.	Event 50	Final PIBAL run accomplished after abort.

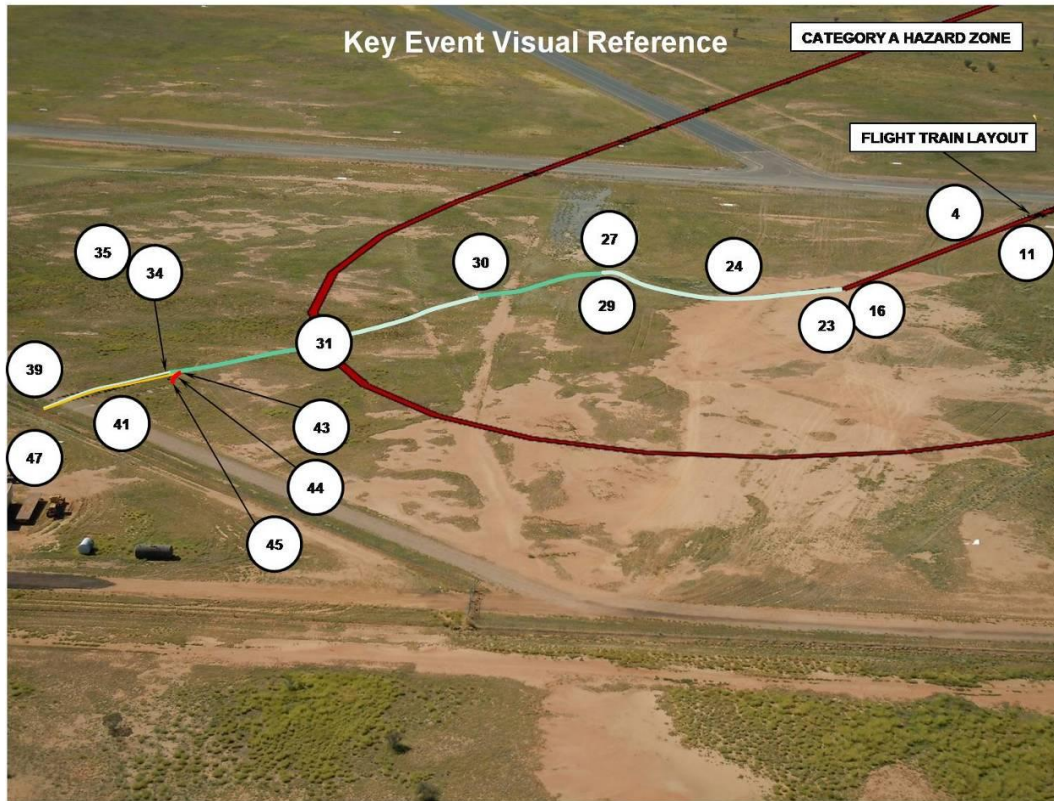


Figure 52. Significant Key Event Visual Reference

### 3.6 Root Cause Analysis

The Root Cause Analysis (RCA) process was aided by the use of the Root Cause Analysis Tool, known as the RCA Tool, version 2.0.0.22, developed by the NASA HQ Office of Safety and Mission Assurance. The MIB accomplished the RCA by first determining: (1) what was unknown, (2) what data were needed, (3) what was thought to be known, and 4) what was definitely known. Following this process, a timeline of events leading up to the mishap was developed and maintained. Next an FT was developed that outlined all known possible causes of the mishap.

As data were gathered, elements on the FT were ruled out if they could not be substantiated, or ruled-in if there were sufficient supporting data, and the timeline was subsequently updated. All of the substantiated causal events, conditions, and contributing factors that were ruled-in were reflected on an E&CFT.

The tree was expanded by continually asking “why” for each element above until all data were exhausted. The RCA Tool produced an .rca file for the mishap which contains all of the data about the events and conditions. The .rca file for this mishap RCA will be stored in IRIS along with this report.

#### 3.6.1 Identification of the Undesired Outcome

The MIB defined the Undesired Outcome as follows: **Unintended release of the Nuclear Compton Telescope payload caused damage to private vehicles, and nearly caused death or injury to the general public.** This defined the scope of the investigation.

### 3.6.2 Fault Tree Analysis

A fault tree analysis (FTA) was accomplished as part of the RCA. The FT was used to capture and identify all known possible causes of the mishap.

Each element of the FT was entered in actor-verb descriptor format. As data were gathered, elements on the FT were ruled out if they could not be substantiated, and such elements are indicated in Section 3.6.4.

All causes, events, conditions, and contributing factors that were ruled-in were carried over on an E&CFT. All elements on the E&CFT were considered causal to the undesired outcome. The FT can be viewed by opening the .rca file in the RCA Tool.

### 3.6.3 E&CFT Analysis

An event and causal factor analysis was accomplished as part of the RCA. Once all the causal events, conditions, and contributing factors were determined on the FT and supported with data, an E&CFT was produced. The tree was expanded by continually asking “why” for the elements above. This process ended when sufficient data were no longer available, or when the answer to the “why” question reached outside of NASA and NASA support contractors. During the investigation, the MIB identified three Undesired Outcomes, each of which would have been sufficient to convene an independent Mishap Investigation Board. Based on the instructions in the appointment letter, the MIB focused on the undesired outcome that was primarily associated with the safety of the public, and heretofore will be discussed throughout this section as the Primary Undesired Outcome (PUO). Two Secondary Undesired Outcomes (SUOs) were identified and will be addressed in Section 3.6.4.

The MIB identified three Proximate Causes that resulted in the Primary Undesired Outcome: **Unintended release of Nuclear Compton Telescope payload caused damage to private vehicles, and nearly caused death or injury to the general public (PUO).** Figure 53 shows the Primary Undesired Outcome and Proximate Causes.

The Proximate Causes are the events that occurred, including any condition(s) that existed immediately before the Primary Undesired Outcome that directly resulted in the occurrence of the Primary Undesired Outcome and, if eliminated or modified, would have prevented the Primary Undesired Outcome. These are also known as the direct causes. First, **the payload separated from the launch vehicle (P1)**, then **the released payload was dragged downwind by the balloon (P2)**, and the condition existed that **people in the general public were in the projected flight path (P3).**



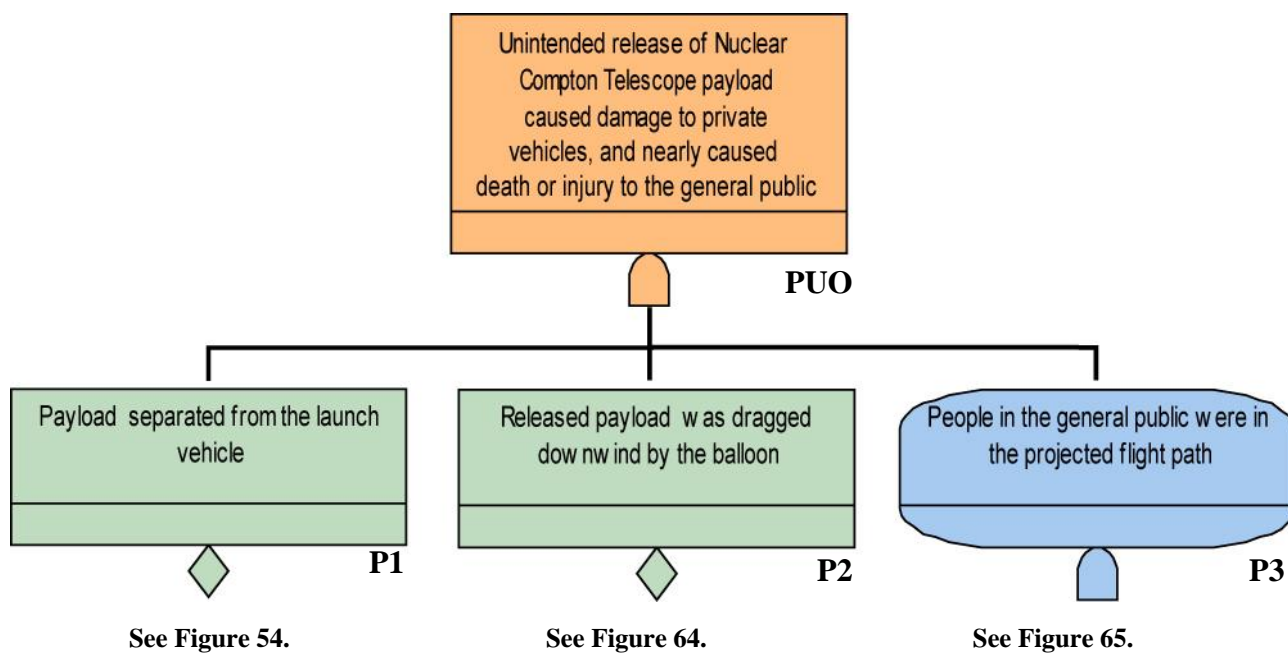
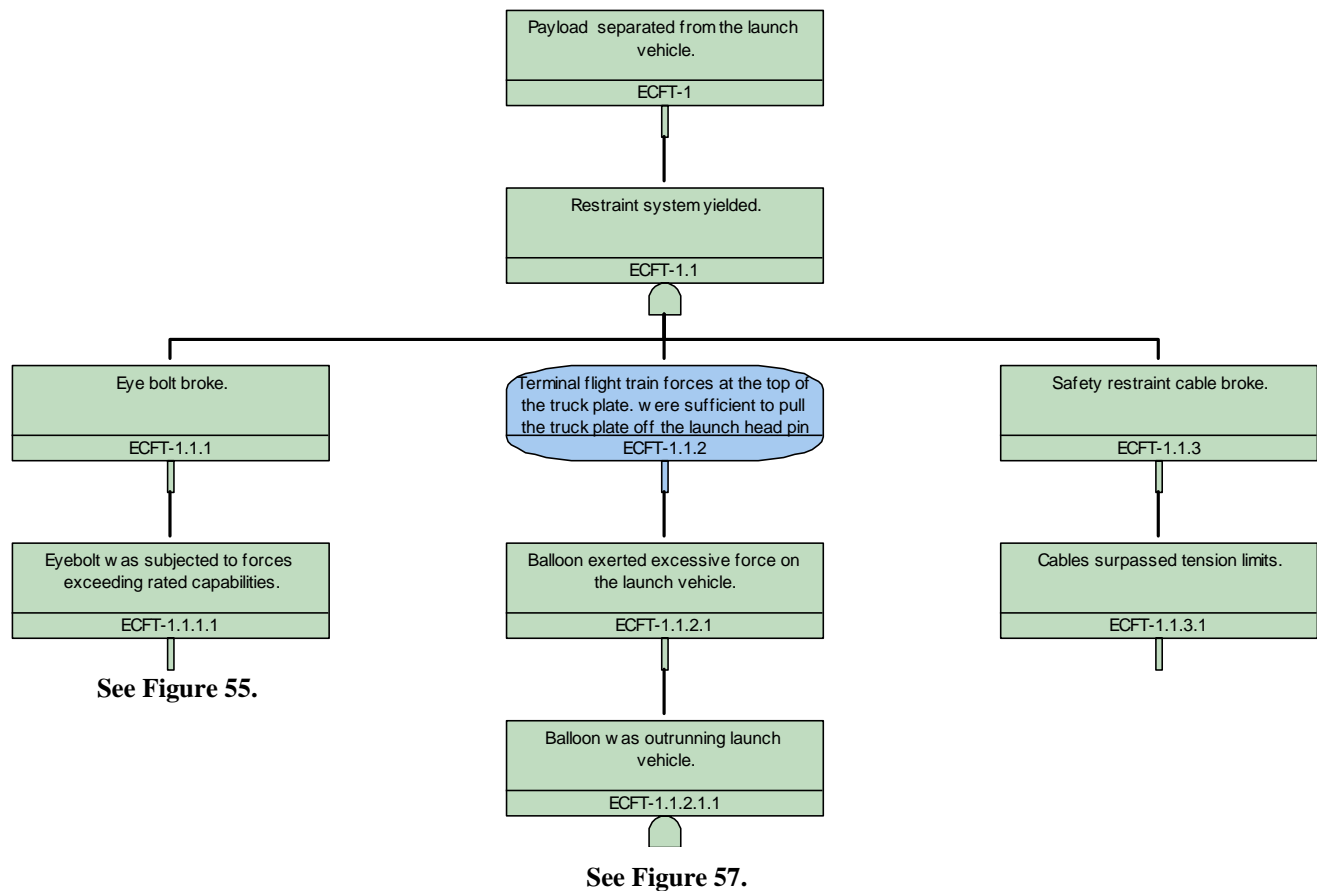


Figure 53. Primary Undesired Outcome and Proximate Causes

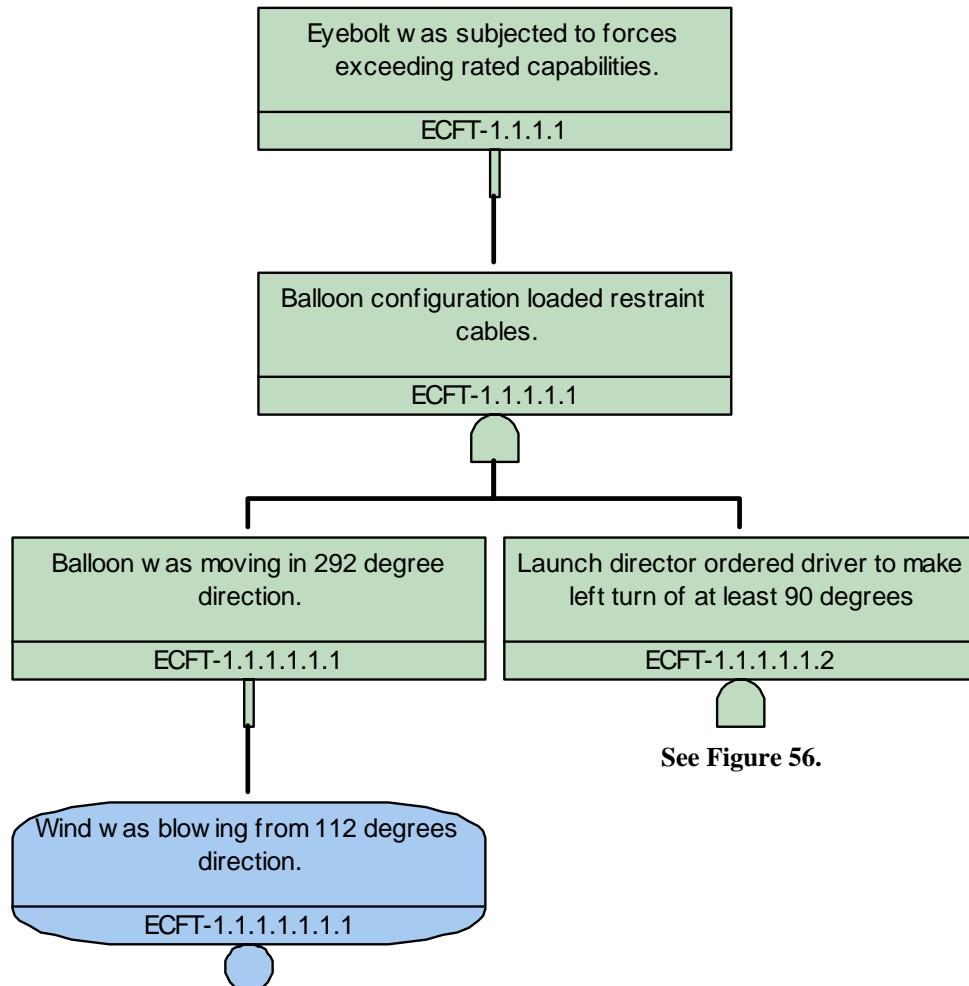


**Figure 54. Payload Separated From Launch Vehicle**

Per video and witness interview, the payload unexpectedly separated from the launch vehicle after several vehicle maneuvers at Alice Springs Airport. The factors leading to the payload separation are as follows:

- A. Eyebolt broke. This was verified by inspection of the impounded hardware. The eyebolt served to hold the safety restraint cable on the truck plate in order to secure the payload to the launch vehicle. According to photographic evidence and analysis, stress on the bolt caused the bolt to exceed its rated capabilities resulting in a structural failure.
- B. Based on video evidence and analysis, terminal flight train forces at the top of the truck plate were sufficient to pull the truck plate off the launch head pin. The truck plate serves as a mechanical interface to secure the payload to the crane head. The alignment of the balloon relative to the launch vehicle combined with the wind speed and direction were sufficient to remove the truck plate from the launch head pin.
  1. The balloon exerted excessive force on the launch vehicle. Based on video evidence, the distance (projected on the ground) between the balloon and the launch vehicle caused a significant horizontal force on the launch vehicle.

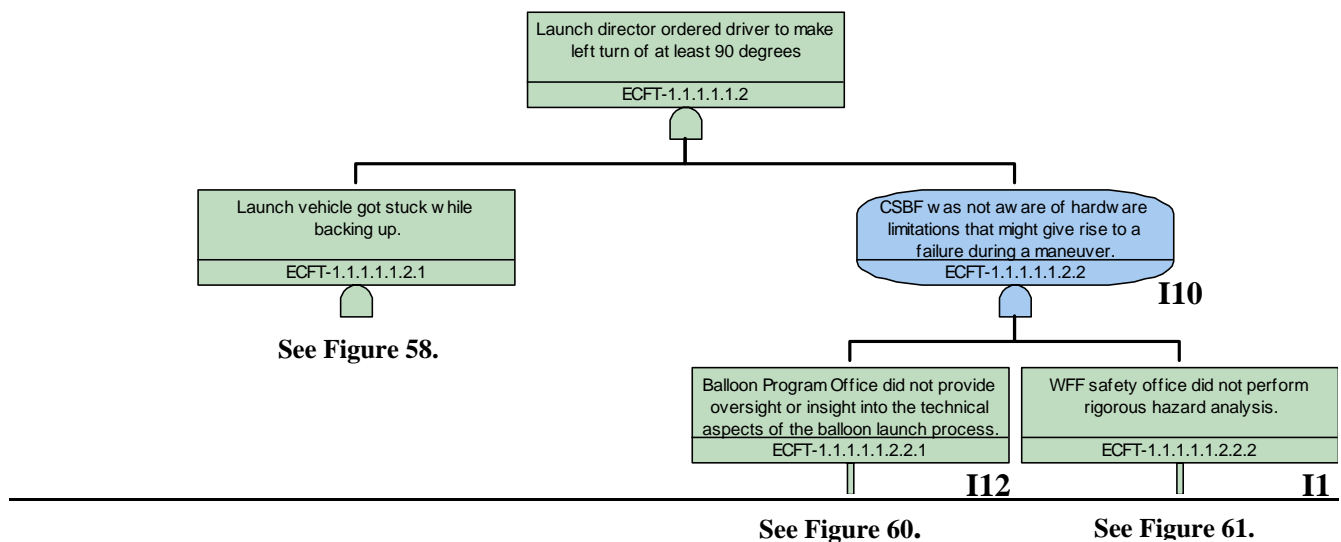
- a. According to video evidence, the balloon was outrunning the launch vehicle and the challenge to catch it was becoming too great.
- C. Safety restraint cable broke. This was verified by inspection of the impounded hardware. The safety restraint cable was used to secure the payload to the launch vehicle. Based on video evidence, test results and analysis, the board determined that the tension in the cable surpassed the cable's rated limits and subsequently the cable broke. The causes follow the same line of reasoning for item A. above and will not be repeated in the report.



See Figure 56.

Figure 55. Eyebolt Was Subjected to Forces Exceeding Rated Capabilities

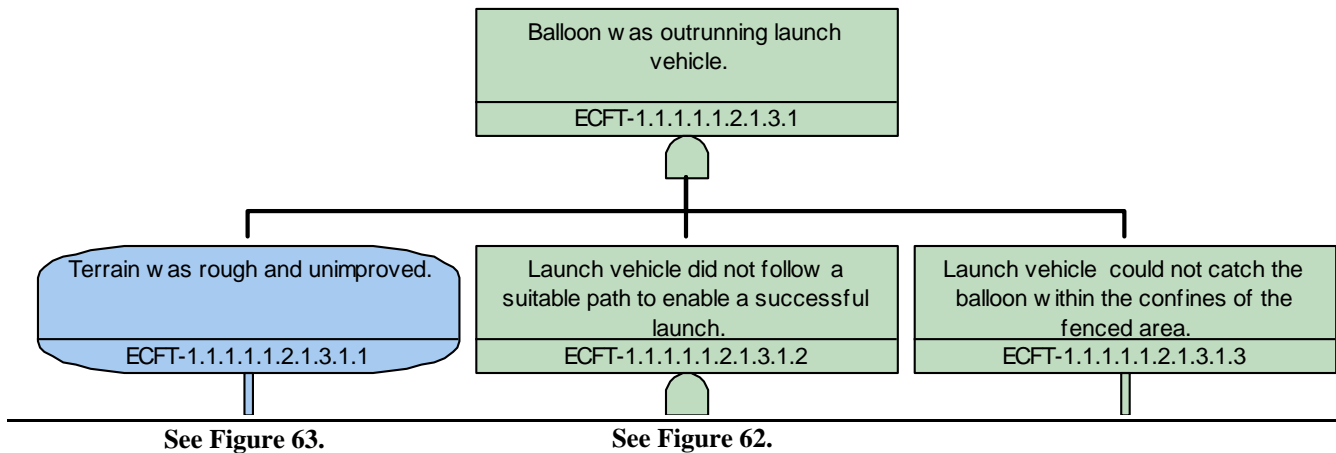
- A. According to video evidence, testing, and analysis, the balloon configuration loaded the restraint cables. The relative position of the balloon to the launch vehicle placed a significant tensile load on the restraint cables that secured the payload to the launch vehicle.
1. According to written meteorology records, the balloon was moving in a 292-degree direction, relative to magnetic north, along with the direction of the wind.
  2. According to video evidence and interview, the launch director ordered the driver to make a left turn of at least 90 degrees. This motion directly opposed the balloon motion, maximizing the stress applied to the system used to secure the payload to the launch vehicle.
    - a. According to meteorology records, the wind was blowing from the 112 degree direction.



**Figure 56. Launch Director Ordered Driver to Make a Left Turn of at Least 90 Degrees**

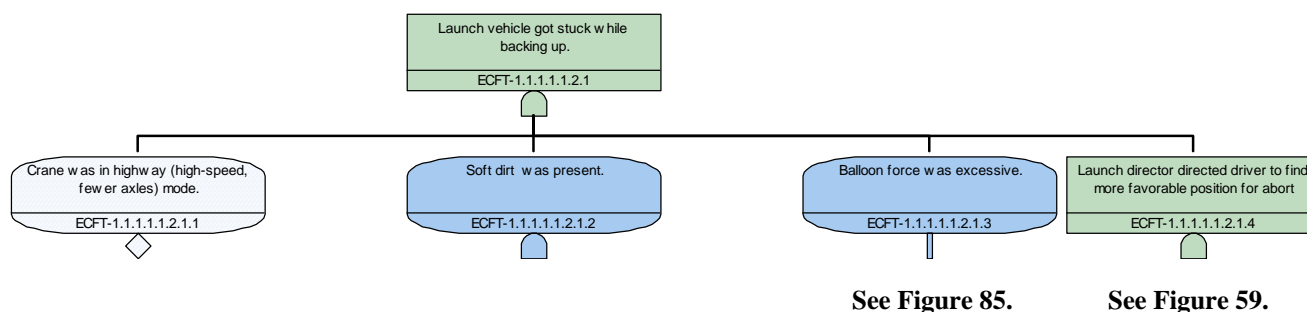
- A. Video evidence and interviews indicated that the launch vehicle got stuck while backing up. The wind and terrain prevented the vehicle from moving a safe distance from the spectators.
- B. Based on interviews and the lack of specific reference in the hardware documentation evidence received by the board, it became apparent that CSBF was not aware of hardware limitations that might give rise to failure during a maneuver. There were no limitations put on what types or durations of maneuvers under what wind or terrain conditions might cause the hardware to exceed its strength limitations. **Intermediate Cause I10**
1. Interview evidence indicated that the BPO did not provide oversight or insight into the technical aspects of the balloon launch process. The technical implementation is left to CSBF through the performance-based contract. **Intermediate Cause I12**

2. Review of documentation indicates that WFF Safety Office did not perform a rigorous hazard analysis. WFF Safety Office is responsible, through RSM 2002 Rev B, for developing the balloon ground safety plan, which includes the hazards in the ground process, including launch. Several hazards are mentioned, but for the most part, the hazards are just those specifically identified with individual payloads, plus the pyrotechnic hazard. **Intermediate Cause I1.**



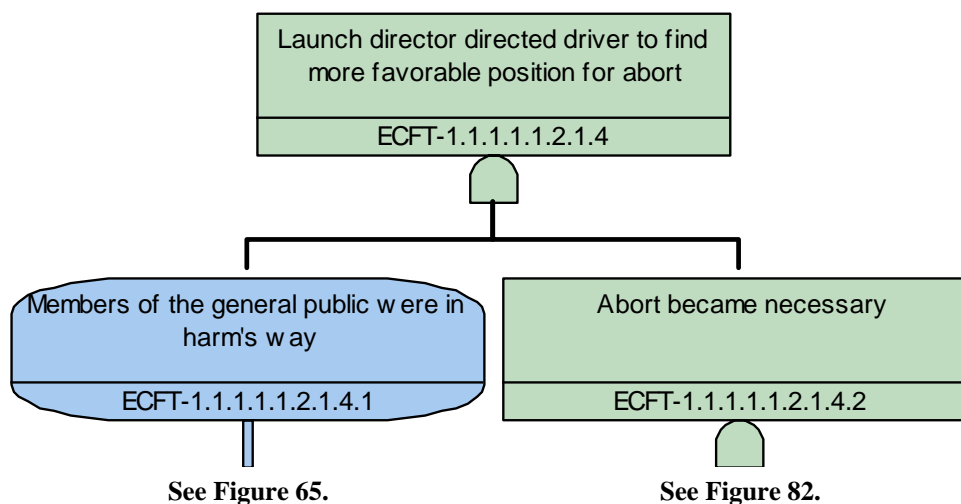
**Figure 57. Balloon Was Outrunning the Launch Vehicle**

- A. The terrain was rough and unimproved. Interviews and site inspection indicate that the terrain was loose and sandy in spots, not an ideal setting for traction.
- B. The launch vehicle did not follow a suitable path to enable a successful launch. Video evidence indicates that the vehicle took inefficient and, in some cases, overly sharp turns to catch the balloon.
- C. Launch vehicle could not catch the balloon within the confines of the fenced area. This is due to the fact that the flight train layout (direction, in particular) restricted the range of motion for the launch vehicle (block not shown). This is indicated from video evidence.



**Figure 58. Launch Vehicle Got Stuck While Backing Up**

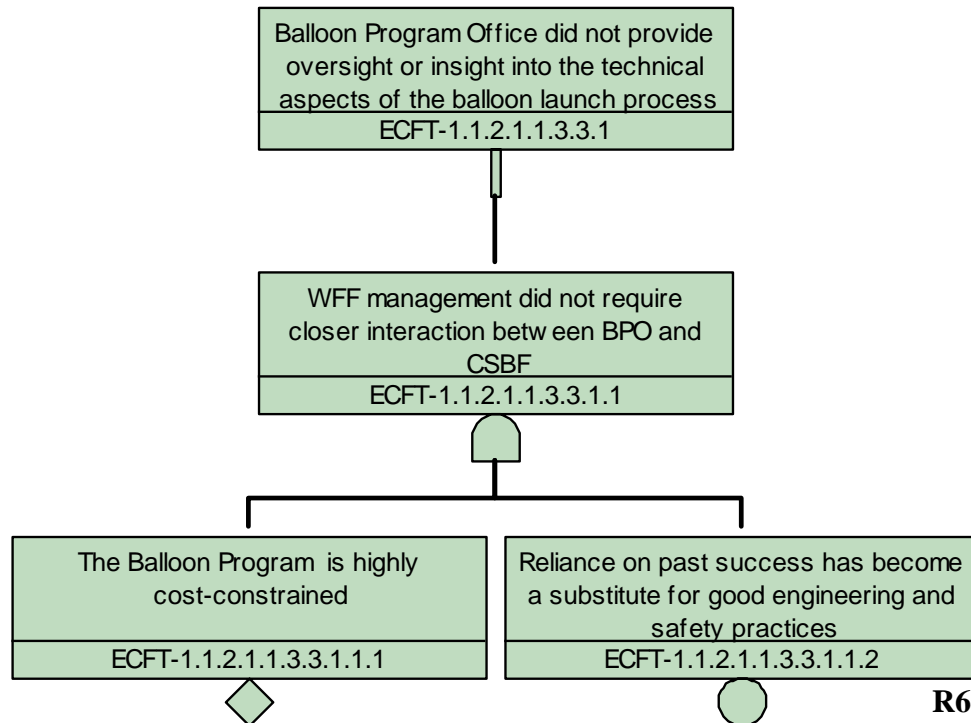
- A. The crane was in highway (high-speed, two-axle) mode, according to information provided from the BPO. This enabled higher speed motion with a better chance to catch the balloon while it was ahead, but there was accordingly less traction when really needed. Strictly speaking, this is a contributing factor, but the fact is that whatever mode the crane was in would have been a contributing factor and there was no determination by the board that any possible mode would have made more of a contribution to this mishap.
- B. Soft dirt was present, based on on-site inspection and interviews. This permitted less traction when there was high tension from the balloon. The rest of this branch is not shown, but the logic leads to a combination of recent rainy weather and Root Cause R6.
- C. Balloon force was excessive. The vehicle could not overcome the force with the traction available. This was based on analysis and simulation.
- D. Launch director directed driver to find more favorable position for abort, based on interview and video evidence. He did not want to abort with people ahead, in-line with the balloon.



**Figure 59. Launch Director Directed Driver to Find a More Favorable Position for Abort**

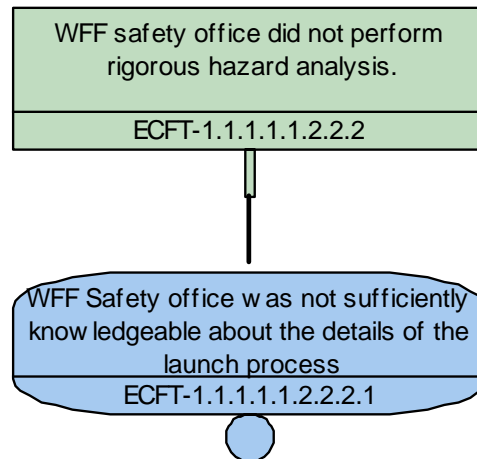


- A. People in the general public were in harm's way. People behind the fence were at risk due to the hazard of falling balloon and flight train hardware.
- B. Abort became necessary. It became clear that based on all of the factors and previous attempts to launch that there would not likely be a chance for successful launch.



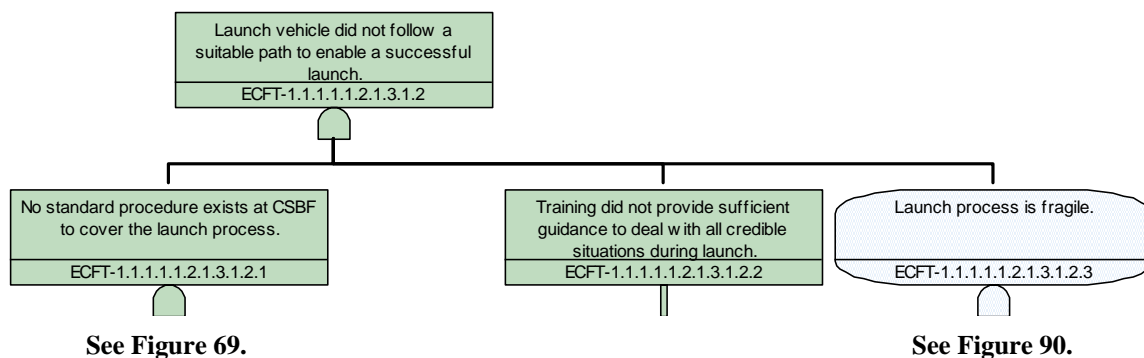
**Figure 60. Balloon Program Office Did Not Provide Oversight or Insight Into the Technical Aspects of the Balloon Launch Process**

- A. WFF management did not require close interaction between BPO and CSBF. This is evident from interviews.
1. The Balloon Program is highly cost-constrained. Interviews have indicated the perception that too much burden on the balloon program with additional requirements “will kill the balloon program.”
  2. Reliance on past success has become a substitute for good engineering and safety practices. Interviews have indicated a consistent theme that the balloon program success rate has been sufficiently high, so therefore there have not been problems to correct or additional scrutiny required. **Root Cause R6.**



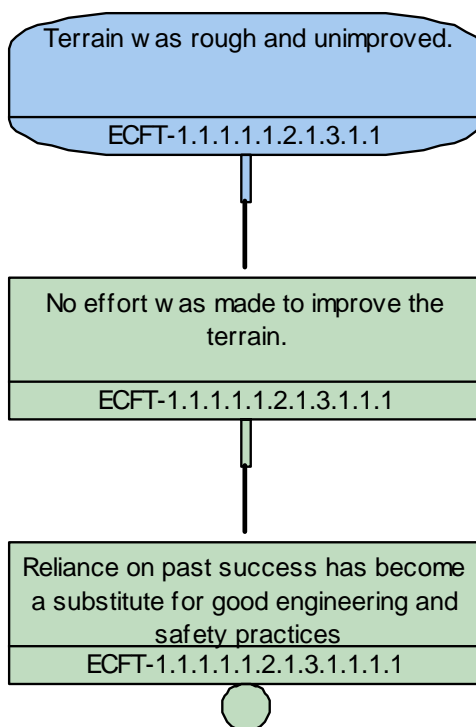
**Figure 61. WFF Safety Office Did Not Perform Rigorous Hazard Analysis**

- A. WFF Safety Office was not sufficiently knowledgeable about the details of the launch process. Interviews and documentation indicate that there is no one in the office cognizant of the details of the operations or hazards involved in launching balloons. **Root Cause R3.**



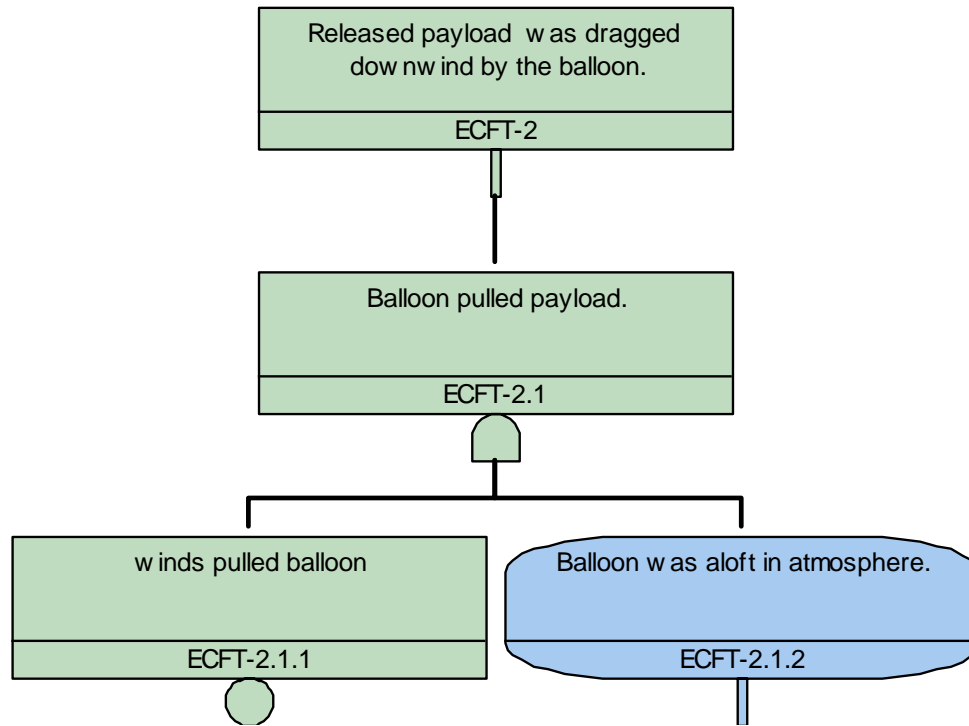
**Figure 62. Launch Vehicle Did Not Follow a Suitable Path to Enable a Successful Launch**

- A. No standard procedure exists at CSBF to cover the launch process. After reviewing all of the procedural documentation, no prescribed process was found for launching the balloon and there was minimal information provided in the documentation for on-the-job training.
- B. Training did not provide sufficient guidance to deal with all credible situations during launch. Interviews indicated that no specific training is provided to deal with anomalies or failed launch attempts. After this point, the logic follows the path shown in Figure 60 and will not be repeated in the report.
- C. Launch process is fragile. Without clear definition and procedures for dealing with anomalies, the launch process is highly sensitive to human error and general awareness as well as environmental conditions, such as terrain and weather. This is evident from interviews and documentation review.



**Figure 63. The Terrain Was Rough and Unimproved**

- A. No effort was made to improve the terrain. Interviews indicate that requests were made to improve the terrain but that the requests never made it to NASA officials.
1. Reliance on past success has become a substitute for good engineering and safety practices. **Root Cause R6.**

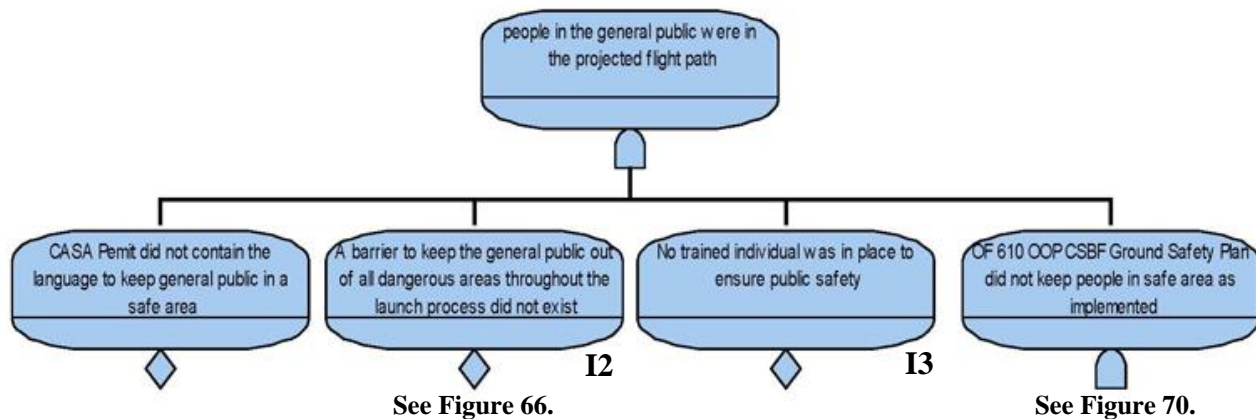


See Figure 67.

**Figure 64. The Released Payload Was Dragged Downwind by the Balloon**

Video evidence indicates that the payload, having been separated from the launch vehicle after the events described in Figure 54, was dragged along the ground, pulled by the balloon under and in the direction of the prevailing wind.

- A. The balloon pulled the payload, as indicated by video evidence.
  - 1. Winds pulled the balloon, as indicated by video evidence as well.
  - 2. The balloon was aloft in the atmosphere. Filled with helium, the balloon continued its motion with the prevailing winds, as indicated by video evidence.



**Figure 65. The General Public Was in the Projected Flight Path**

An unusual situation occurred in the Balloon mishap at Alice Springs in which people of the general public, namely spectators, were in the projected flight path. The conditions leading to this were in essence a collection of failed or missing (but perhaps expected or perceived) barriers and controls, described as follows. This situation is indicated by video and photographic evidence, and interviews.

- A. A permit was issued from the Australian Civil Aviation Safety Authority (CASA) that approved the area around Alice Springs airport for operation of a heavy balloon, based on documentation. The permit identifies an “approved area” as the Alice Springs airport, denoted by a single latitude/longitude point. This is ambiguous in and of itself in that there is a fence that goes around most of the airport, keeping unauthorized personnel out. There is an area where many of the people were and where the payload traversed after becoming separated from the launch vehicle that, oddly enough, is also the area that happens to be on the airport property but is outside of the security fence. While at first glance it appears that this permit is intended to establish a safe area to protect the public, the ambiguity of the boundaries of the area and the lack of specific reference to people in the area during the launch indicate that it does not address public safety.
- B. There was no barrier in place to keep the general public out of all dangerous areas throughout the launch process. There was free access to a broad area downwind of the balloon to spectators and passers-by on public roads. There was a fence that kept unauthorized personnel out of an area downwind of the balloon but it still allowed people to be present within a hazardous area. This is indicated by video evidence, documentation, interview, and on-site assessment.

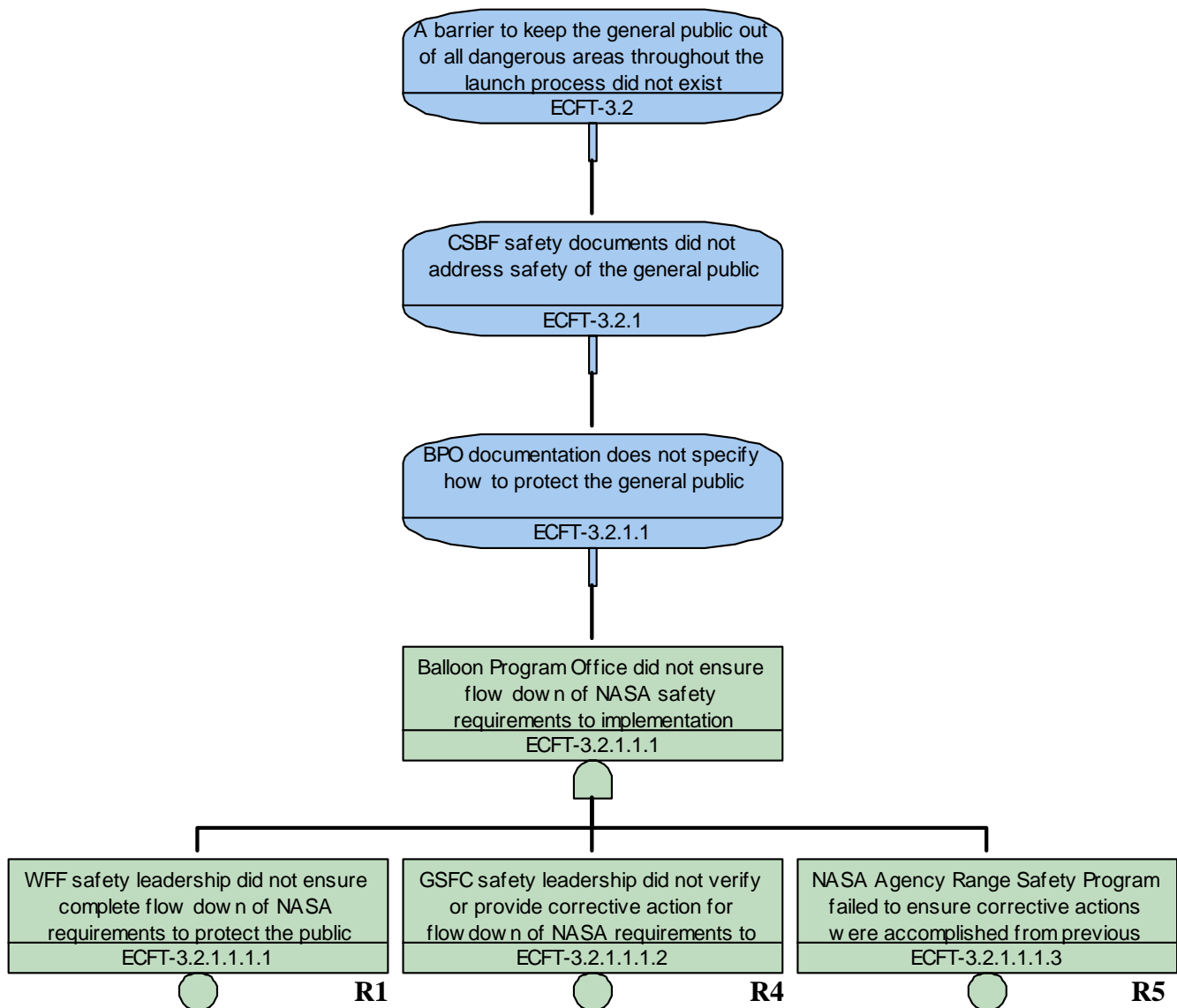
#### **Intermediate Cause I2**

- C. No trained individual was independently in place to ensure range safety. The closest individual to a range safety officer was the campaign manager, but his primary responsibility was to ensure mission success and during launch he performed the call to drop the collars from the balloon. Hence, he lacked independence and did not have a priority allocation of time to focus on safety. The launch director had a general responsibility to halt the launch process if the

situation appeared unsafe, but he lacked independence as well and his primary responsibility was to direct the launch vehicle to track the balloon and launch at the appropriate time.

Evidence was in documentation and interview. This follows the same logic flow as in Figure 66 and will not be repeated here. **Intermediate Cause I3**

- D. The Balloon Ground Safety Plan did not keep people in a safe area as implemented as evidenced by video, documentation, and interview. The ground safety plan identified a set of hazards, but did not identify the actual hazard that was involved in this mishap--that of a heavy payload with high potential and mechanical energy. The plan defined a hazard zone, but it was not clear whether the zone was fixed or moving. There were no markings for the zone; the crew identified the boundaries by landmarks in the terrain. There was nothing to prevent the launch vehicle or targets from breaching the zone and nothing to indicate when the zone would be breached. If the zone were moving, there would be no practical way to use it as a barrier. If the zone were fixed, the size wasn't sufficient to cover the actual hazard area.

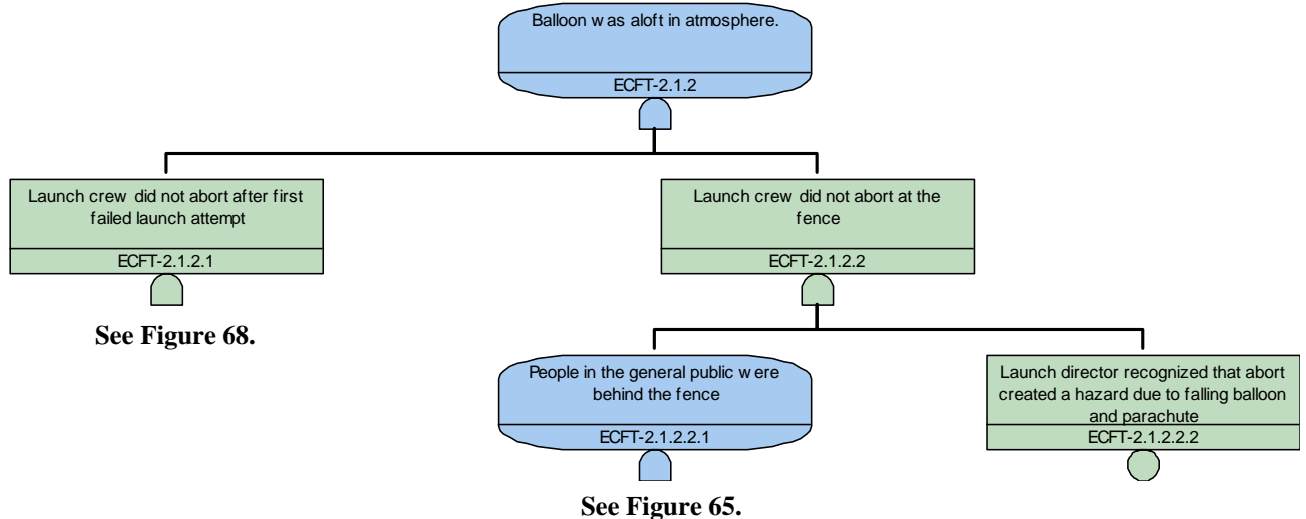


**Figure 66. A Barrier to Keep the General Public Out of All Dangerous Areas Throughout the Launch Process Did Not Exist**

- A. Neither CSBF nor Balloon Program Office safety documents address safety of the general public. Safety documentation of CSBF and the BPO lacks any provision for dealing with spectators and passers-by during the launch process.
1. BPO did not ensure flow down of NASA safety requirements to implementation. From RSM 2002 Rev B, BPO was delegated the responsibility to ensure safety requirements were implemented at the launch site, but lacking provisions for dealing with people appearing at the launch site indicates a failure to protect the general public due to the hazards associated with the launch process and the ability for people to gain proximity to the launch. This lack of adequate assurance of public safety amidst credible hazards contradicts the requirements in several NASA safety documents, to include NPR 8715.3 and NPR 8715.5.



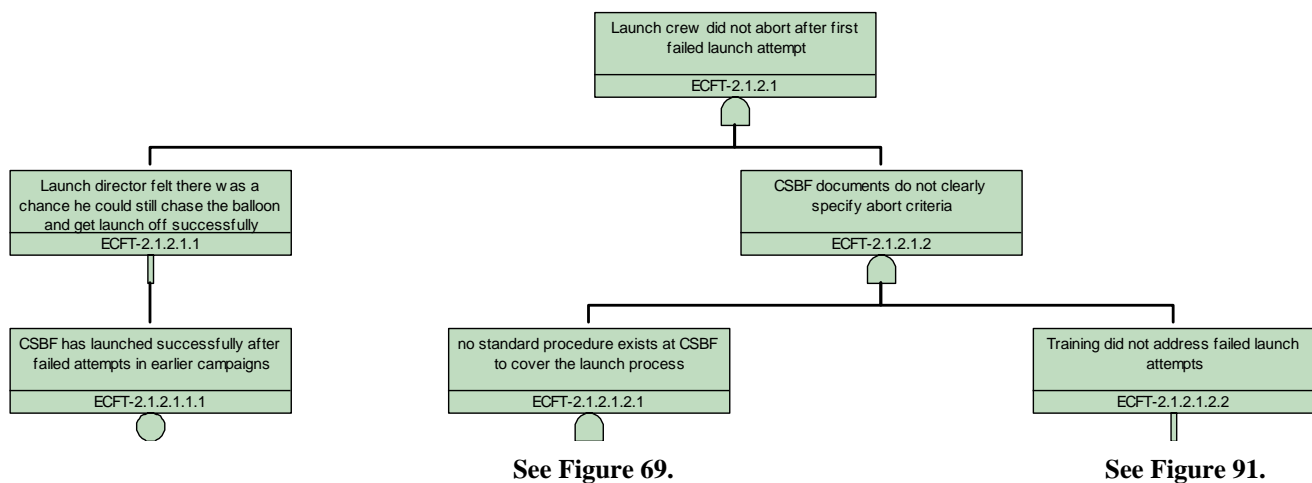
- a. WFF safety leadership did not ensure complete flow down of NASA requirements to protect the public. While the BPO is delegated the responsibility for implementation of safety requirements in balloon activities, WFF safety leadership, to include at a minimum the WFF Safety Office and Code 800 management was not aware that public safety was endangered during balloon activities. Such awareness would have likely prevented the undesired outcome. **(Root Cause R1)**
- b. GSFC safety leadership did not verify or provide corrective action for flow down of requirements to protect the general public. GSFC safety leadership responsible for safety of activities conducted by WFF did not ensure that the appropriate safety practices were in place to protect the public in all such activities. **(Root Cause R4)**
- c. NASA Agency Range Safety Program failed to ensure corrective actions were accomplished from previous agency audits. Several items from a 2002 audit had not been closed, but in particular one item found that “Balloon Program payloads are potentially hazardous to the public and should be managed consistent with other hazardous, uninhabited programs” and this item was still not closed. A finding that activities endanger the public did not prompt diligent follow-up and elevation to the highest level of NASA to prevent such activities from continuing without proper mitigations. **(Root Cause R5)**



**Figure 67. Balloon Was Aloft in the Atmosphere**

- A. The launch crew did not abort after the first failed launch attempt. When the launch director was unable to get the pin to release from pulling on the lanyard, he decided to chase the balloon for another attempt. Had they aborted after the first attempt, the undesired outcome would not have occurred. This was evident from video evidence and interview.

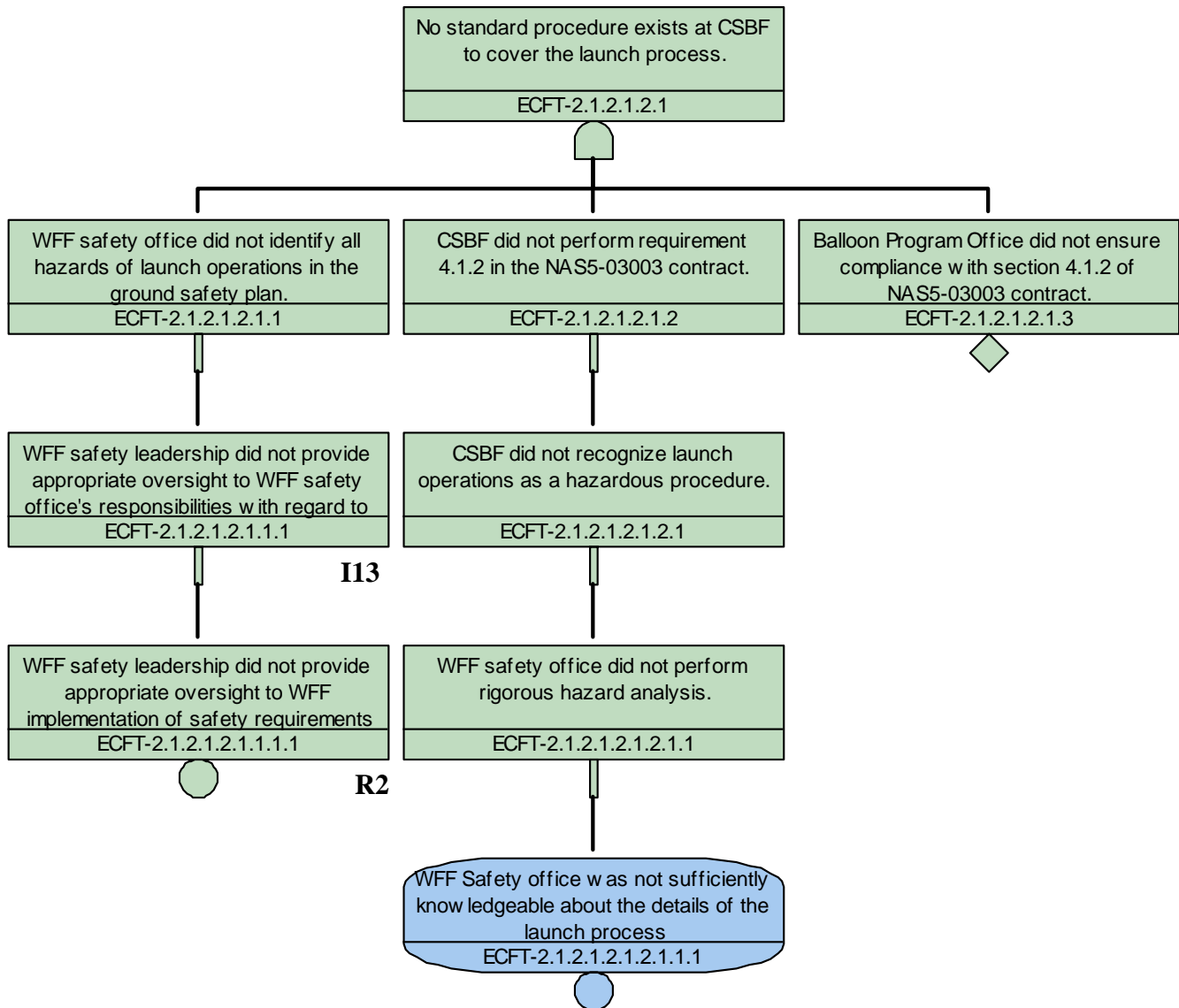
- B. The launch crew did not abort at the fence. After the launch vehicle had breached any possible interpretation of the hazard zone, a physical limit was reached when it came to a fence. At this time, the launch director recognized that there was no further hope for a successful launch, but he did not abort the balloon. This was revealed from video evidence and interview.
1. People from the general public were located immediately behind the fence, as indicated in video evidence and interview. This leads to the same set of events in the branch shown in Figure 65.
  2. The launch director recognized that abort created a hazard due to the falling balloon and parachute as indicated from interview and video evidence. This hazard was due to heavy components in the flight train, balloon, and the parachute and aborting would risk these components falling on anyone in the vicinity. Hence he realized that he needed to move to a different location to abort. However, had he remained in that position, if there were an individual with responsibility for protecting the public, the people could have been moved to a safe location in order to ensure a safe abort.



**Figure 68. Launch Crew Did Not Abort After the First Failed Launch Attempt**

- A. The launch director felt there was a chance he could still chase the balloon and get the launch off successfully. Hence, he proceeded forward to get into a better position under the balloon. In fact, had there been no fence or people around, evidence indicates that he eventually would have caught the balloon. This was evident from interview and video evidence.
1. CSBF has launched successfully after failed attempts in earlier campaigns. Hence there was no expectation that they wouldn't eventually get into a proper position to launch. This was indicated from interviews.
- B. CSBF documents do not clearly specify abort criteria. Abort is performed only as an instinctual action and not based on clear guidance.

1. Based on interview and documentation review, it became clear that no standard procedure exists at CSBF to cover the launch process. It is entirely reliant on human observation and decision-making.
2. Training did not address failed launch attempts. In general, launch directors are not given clear direction for the possible range of contingency and anomalous situations.

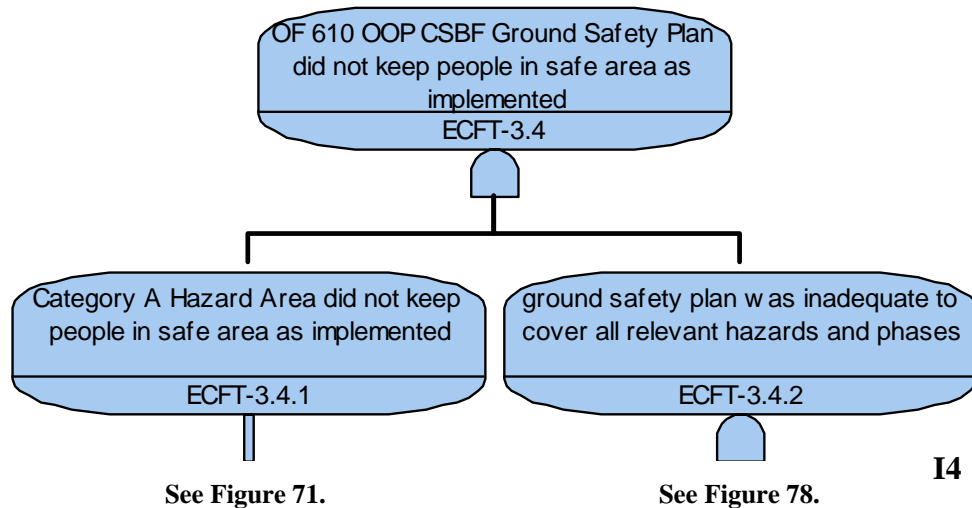


**Figure 69. No Standard Procedure Exists at CSBF to Cover the Launch Process**

- A. WFF safety office did not identify all hazards of launch operations in the ground safety plan. In particular, the energy in the hanging payload was not identified as a hazard. Nor were the hardware in the balloon or parachute identified as hazards, although they were identified as hazards by the launch director when the vehicle approached the fence. This was evident from

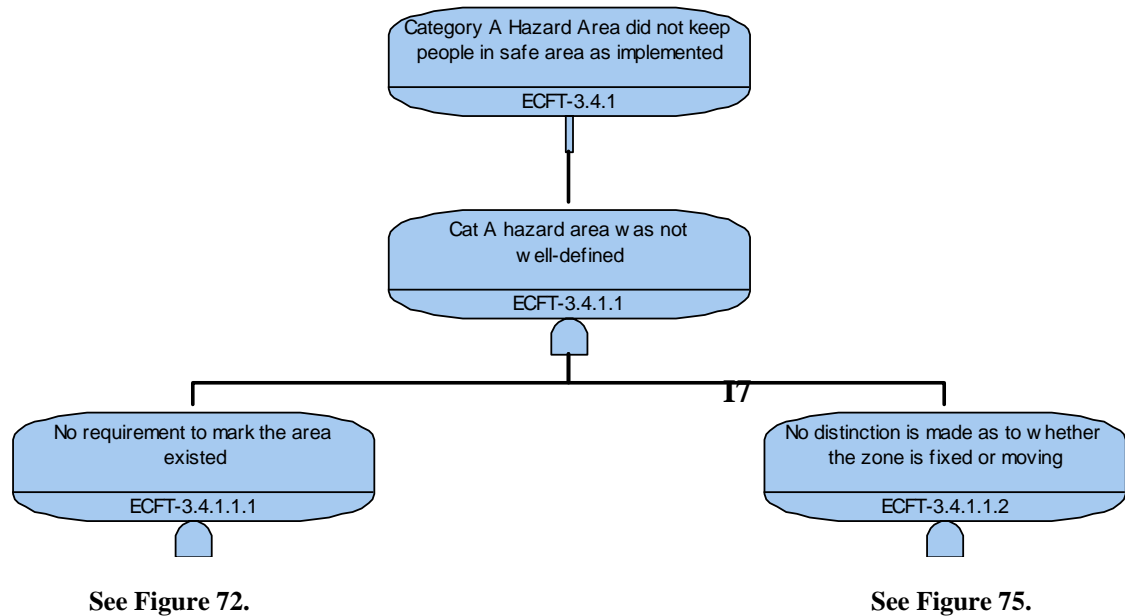
reviewing ground safety documentation, including the ground safety plan. Given that the hazards of launch operations were not identified, there was no recognition that a procedure would be required to cover the launch process.

1. WFF safety leadership did not provide appropriate oversight to WFF safety office's responsibilities with regard to the balloon program. WFF safety leadership did not pay particularly close attention to the broad set of safety practices within the balloon program, particularly anything outside of over flight casualty assessments. This is evident from interview, documentation, and video evidence. **Intermediate Cause I13**
  - a. WFF safety leadership did not provide appropriate oversight to WFF implementation of safety requirements. **Root Cause R2.**
- B. CSBF did not perform requirement 4.1.2 in the NAS5-03003 contract, as evident from documentation and interviews. Requirement 4.1.2 states that written procedures are required for any hazardous procedure and given that the launch process involves many hazards, it requires written procedures.
  1. CSBF did not recognize launch operations as a hazardous procedure. Generally, the hazards were identified within the unique payloads, in the pyrotechnics, and in over flight. The rest of the logic flows as in Figure 61, as the lack of a full hazard analysis by the WFF safety office (as required in RSM 2002 Rev B, where WFF safety office is responsible for writing the ground safety plan) allowed this key hazard to slip through the cracks. This is indicated by documentation, in particular within the Ground Safety Plan.
- C. Balloon Program Office did not ensure compliance with section 4.1.2 of NAS5-03003 contract. BPO did not ensure that procedures were written to cover the launch process.



**Figure 70. The OF 610 CSBF Ground Safety Plan Did Not Keep People in a Safe Area as Implemented**

- A. The Category A Hazard Area did not keep people in a safe area as implemented. Although generally the launch crew was aware of a hazard area, known by several different names, it was ineffective at keeping people out of harm's way. This was evident from video evidence and interview.
- B. The ground safety plan was inadequate to cover all relevant hazards and phases according to documentation review. The plan did not cover the detailed actions generally performed in the launch phase and it failed to identify several hazards, including that of the stored energy in a hanging payload and the hardware present in the balloon and parachute that could land on people or property in the case of an abort. **Intermediate Cause I4**

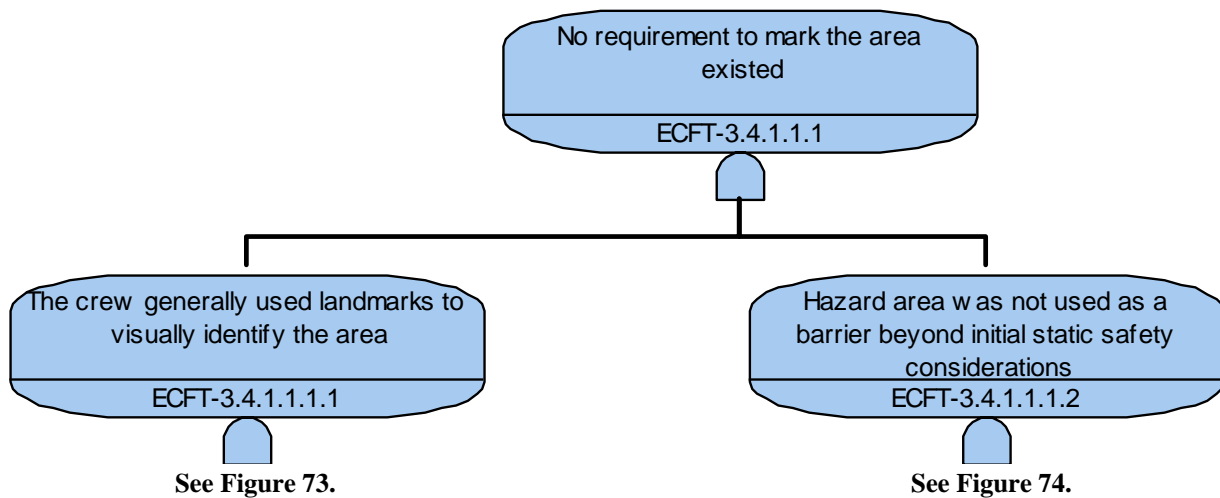


**Figure 71. The Category a Hazard Area Did Not Keep People in a Safe Area as Implemented**

- A. The Category A Hazard Area was not well-defined. There are several different interpretations of the area within the BPO and CSBF. This was evident from review of documentation.

**Intermediate Cause I7**

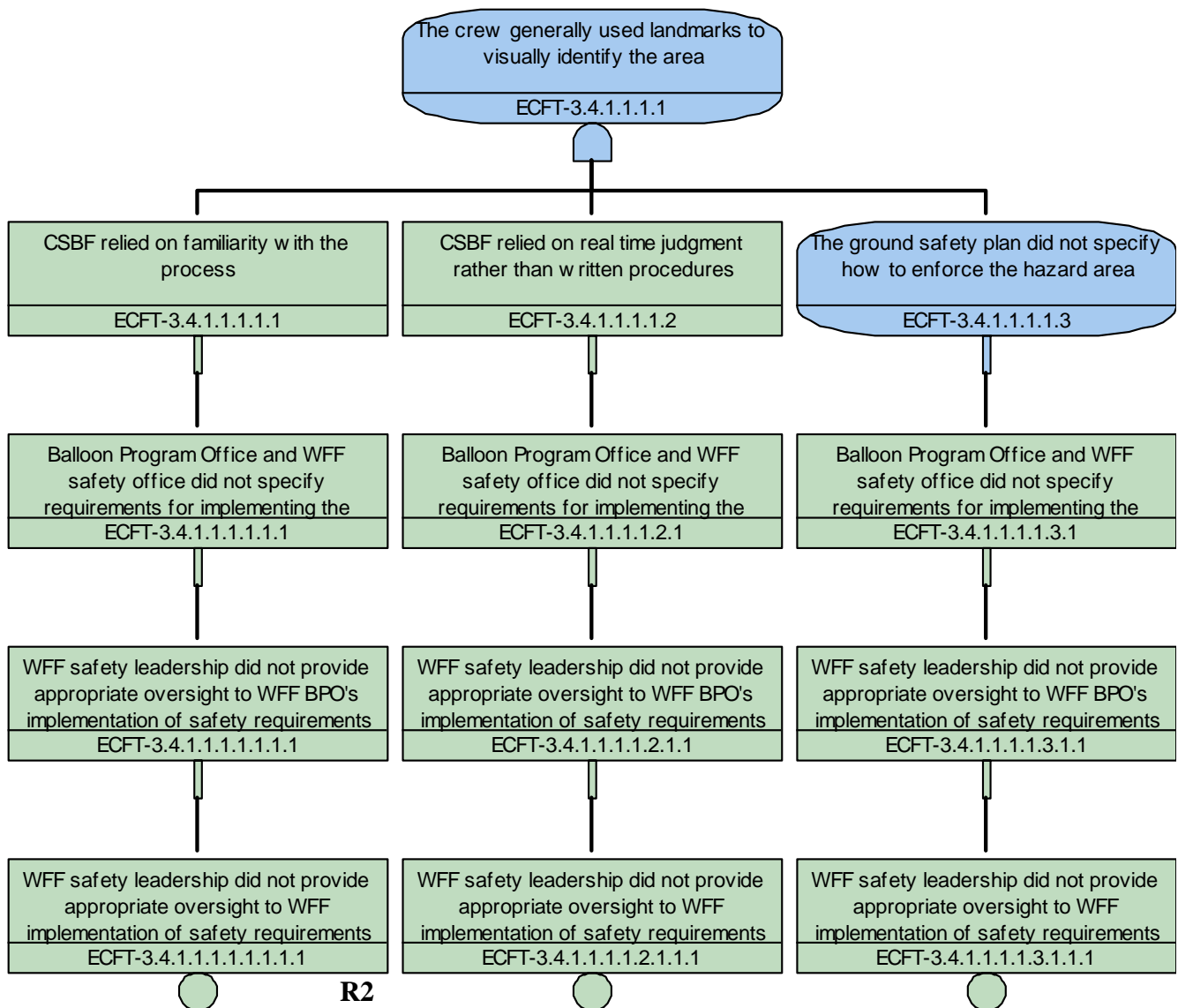
1. No requirement to mark the area existed, based on review of documentation. Henceforth, there was no way for anyone to tell when it was close to being breached.
2. No distinction is made as to whether the zone is fixed or moving, as indicated from documentation. The definition of the zone would tend to lean towards it being a moving area, but a moving area would not be implementable. A fixed area would be insufficient to cover the most relevant hazards during launch. The BPO believes the zone to be moving while CSBF believes the zone to be fixed.



**Figure 72. No Requirement to Mark the Area Existed**

- A. The crew generally used landmarks to visually identify the area. Interviews indicate that during set up for launch the crew would loosely walk off the hazard area and take mental note of identifying features at the edges of the zone.
- B. The hazard area was not used as a barrier beyond initial static safety considerations. There is no evidence that there is any consideration of the Category A Hazard Area once the launch vehicle begins to move.





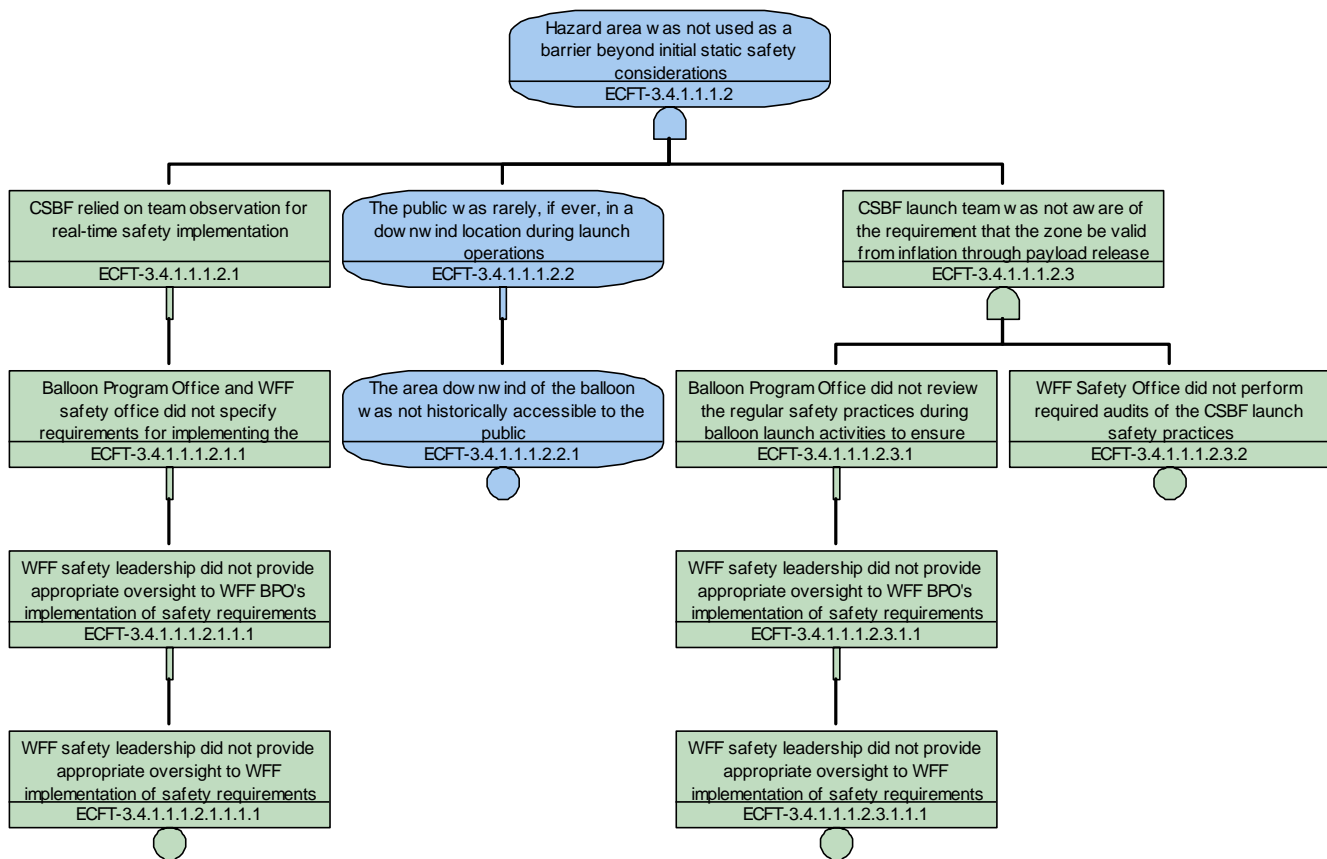
**Figure 73. The Crew Generally Used Landmarks to Visually Identify the Area**

- A. CSBF relied on familiarity with the process. Rather than explicitly marking things off and writing down procedures, CSBF based successful operations on experience and training, which left much susceptible to human error or lack of understanding of what to do in contingency or anomalous situations. This was evident from interviews and documentation.
1. BPO and WFF safety office did not specify requirements for implementing the hazard area. This responsibility was fully contractually delegated to the CSBF but given the safety implications, both should have been knowledgeable about how this was being performed. This was evident from interviews and documentation.
    - a. WFF safety leadership did not provide appropriate oversight to WFF BPO's implementation of safety requirements. Interviews indicate that the balloon program has

operated with minimal direct interaction from WFF safety leadership.

- i. WFF safety leadership did not provide appropriate oversight to WFF implementation of safety requirements. **Root Cause R2.**

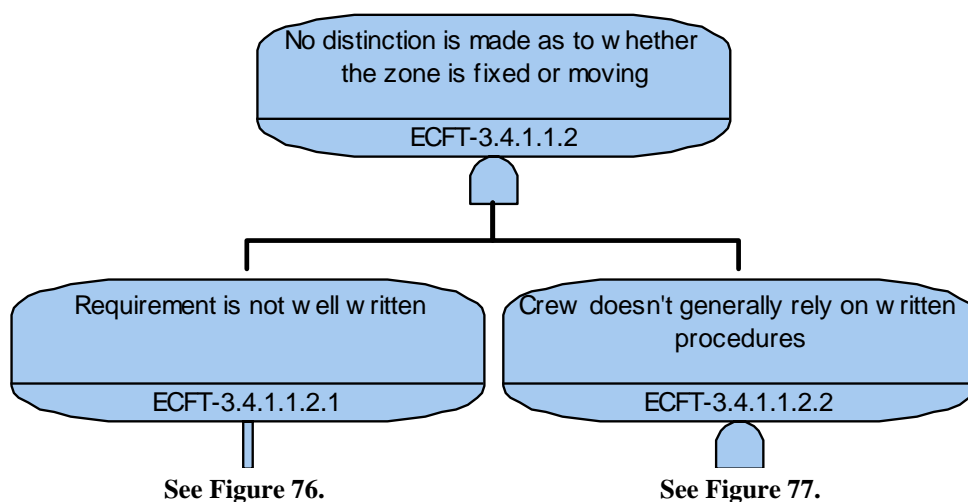
- B. CSBF relied on real-time judgment rather than written procedures. This is based on documentation and interview and the logic flow is the same as that in item A. above.
- C. The ground safety plan did not specify how to enforce the hazard area. This is based on documentation and the logic flow is the same as that in item A. above.



**Figure 74. The Hazard Area Was Not Used as a Barrier Beyond Initial Static Safety Considerations**

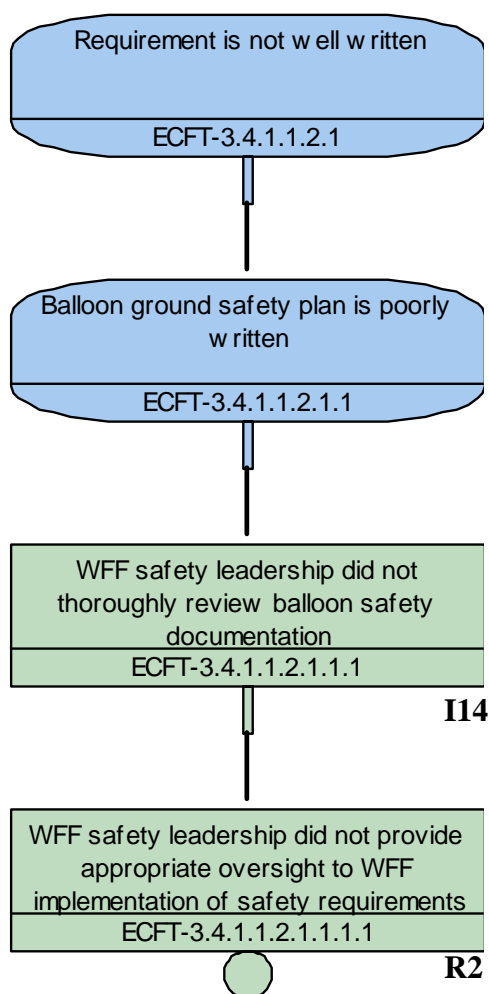
- A. CSBF relied on team observation for real-time safety implementation. There was no coordinated effort or centralized responsibility for safety and this mode leaves much to having problems slip through the cracks. This was evident from interviews and documentation.
  1. BPO and WFF Safety Office did not specify requirements for implementing the safety zone. Safety documentation written and approved by BPO and WFF defines the zone in general terms but does not indicate any requirements for implementation, as indicated in the Ground Safety Plan.

- a. WFF safety management did not provide appropriate oversight to WFF BPO's implementation of safety. The extent of oversight does not go beyond knowledge of the safety documentation, primarily the ground safety plan and the balloon risk analysis. This was evident from interviews. The logic flow continues as in Figure 73.
- B. The public was rarely, if ever, in a downwind location during launch operations. This was not a situation that the team had experienced, according to interviews.
  1. The area downwind of the balloon was not historically accessible to the public. It just so happened that the layout of the balloon on this day was such that publicly accessible points were in the proximity downwind. This was indicated in interviews.
- C. CSBF launch team was not aware of the requirement that the zone be valid from inflation through payload release. There was no evidence that any attention was paid to the zone during the process of chasing the balloon and trying to launch.
  1. BPO did not review the regular safety practices during balloon launch activities to ensure compliance with existing requirements. BPO's primary awareness of safety practices was in knowledge of the ground safety plan and Balloon Risk Analysis, but little knowledge of what was actually being practiced in the field.
    - a. WFF Safety leadership did not provide appropriate oversight to WFF BPO's implementation of safety. WFF BPO's implementation of the safety during balloon launches was "out-of-sight, out-of-mind" to WFF safety leadership. The logic flow continues as in Figure 73.
  2. According to interviews, WFF Safety Office did not perform required audits of the CSBF launch safety practices. These audits were to be in response to the 2002 audit by NASA HQ OSMA. However, they were never performed.



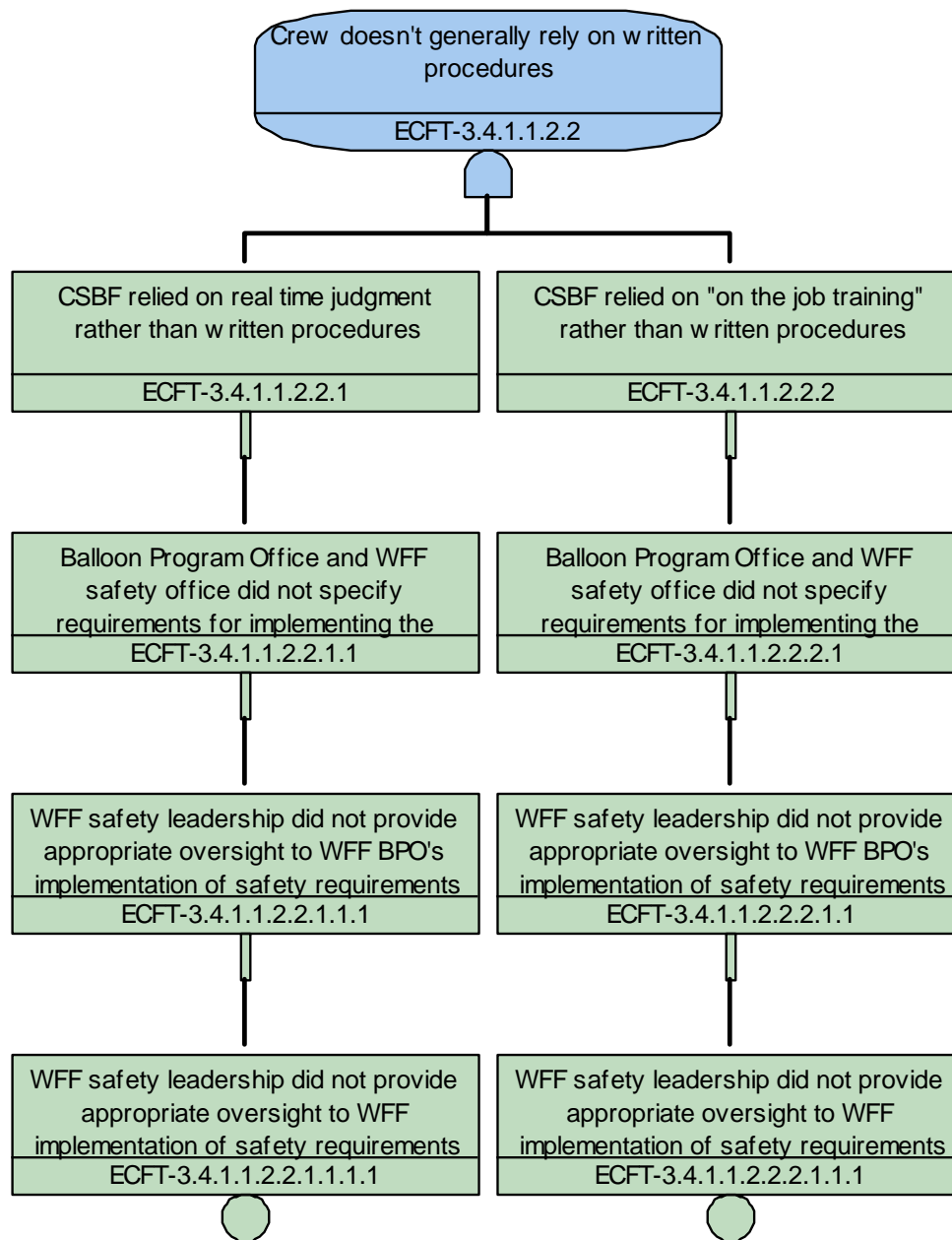
**Figure 75. No Distinction Is Made as to Whether the Zone Is Fixed or Moving**

- A. The requirement is not well-written. There is no specific discussion about what happens when the vehicle moves or how one would determine whether the zone is breached in practice. This is evident from review of the Ground Safety Plan.
- B. The crew doesn't generally rely on written procedures, according to documentation and interviews. Training and experience are the primary means to successfully launch balloons.



**Figure 76. Requirement Is Not Well Written**

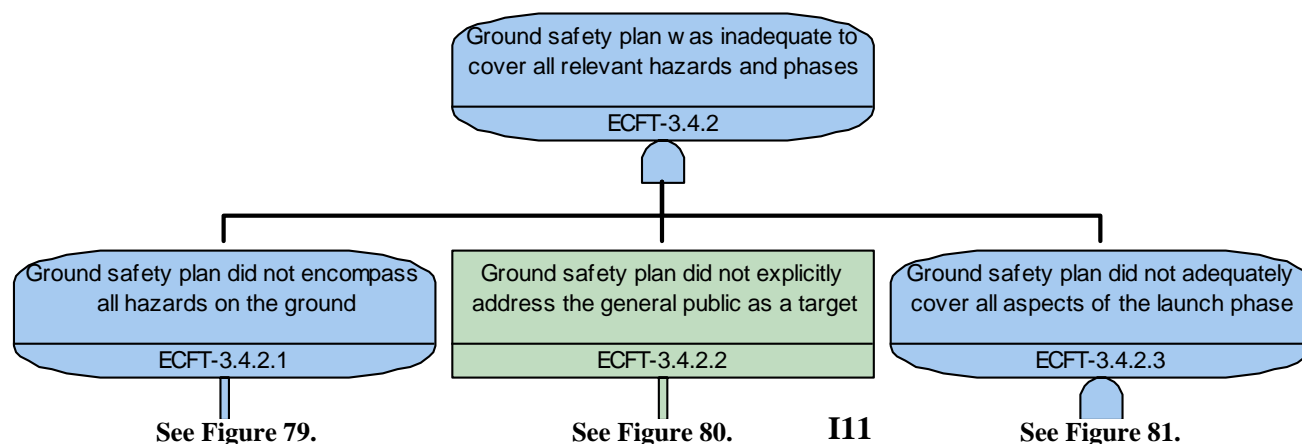
- A. The balloon ground safety plan is poorly written. It leaves out many of the details during the launch process and does not address all hazards.
1. WFF safety leadership did not thoroughly review balloon safety documentation. There is much ambiguous language in the documentation, hazards are not covered completely, there is no provision to protect the public except in the over flight phase, and it does not completely cover all phases of balloon operations. **Intermediate Cause I14**
    - a. WFF safety leadership did not provide appropriate oversight to WFF implementation of safety requirements. **Root Cause R2.**



**Figure 77. Crew Does Not Generally Rely on Written Procedures**

Both of the following items lead through the same path as in branch “A” of Figure 74.

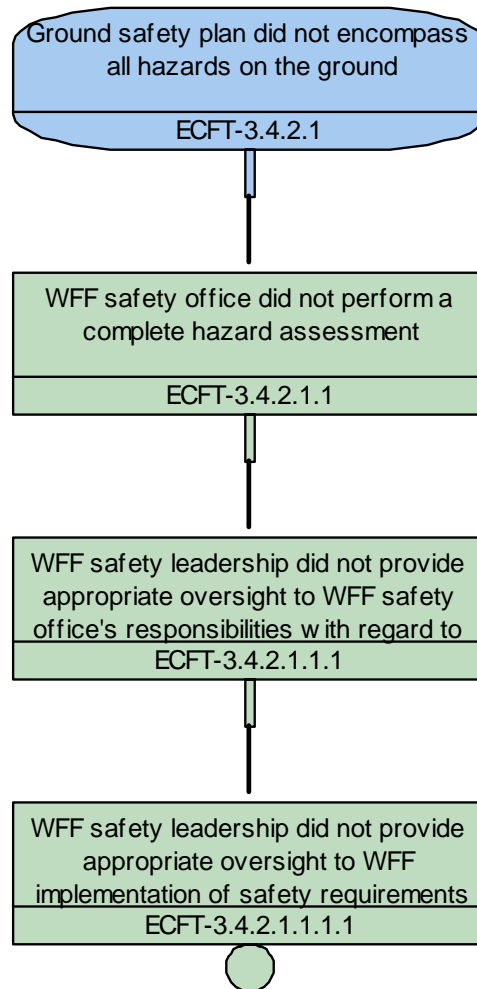
- A. CSBF relied on real-time judgment rather than written procedures. The general approach is to train the launch crew in a general sense and have them respond to the events with good judgment. This is according to interviews and documentation.
- B. CSBF relied on “on-the-job training” rather than written procedures. On-the-job training is used in place of explicit rules and procedures. This is according to interviews and documentation.



**Figure 78. The Ground Safety Plan Was Inadequate to Cover All Relevant Hazards and Phases**

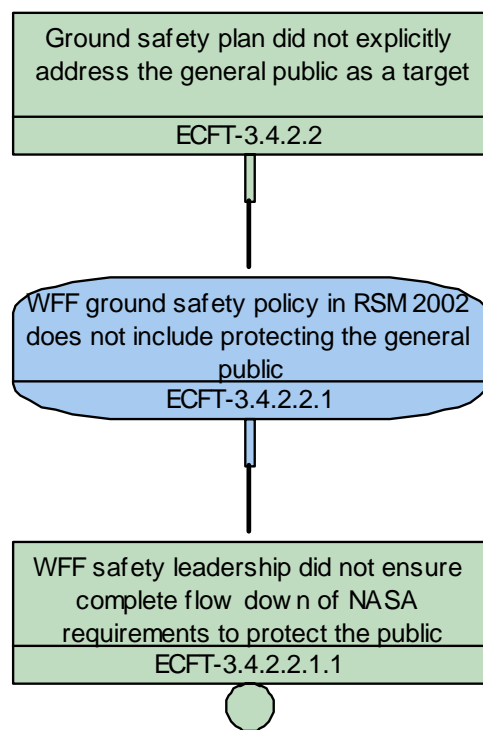
- A. The ground safety plan did not encompass all hazards on the ground. For example, neither the hazard of a hanging heavy payload, nor those of the balloon or parachute and associated hardware falling due to an abort were acknowledged.
  - B. The ground safety plan did not explicitly address the general public as a target. The plan only focused on personnel and keeping unauthorized personnel out of a hazard zone, but did nothing to address hazards to spectators or passers-by. **Intermediate Cause I11**
  - C. The ground safety plan did not adequately cover all aspects of the launch phase. The process of moving the crane around to chase the balloon, attempting launch, and the process and requirements for abort are not thoroughly covered.
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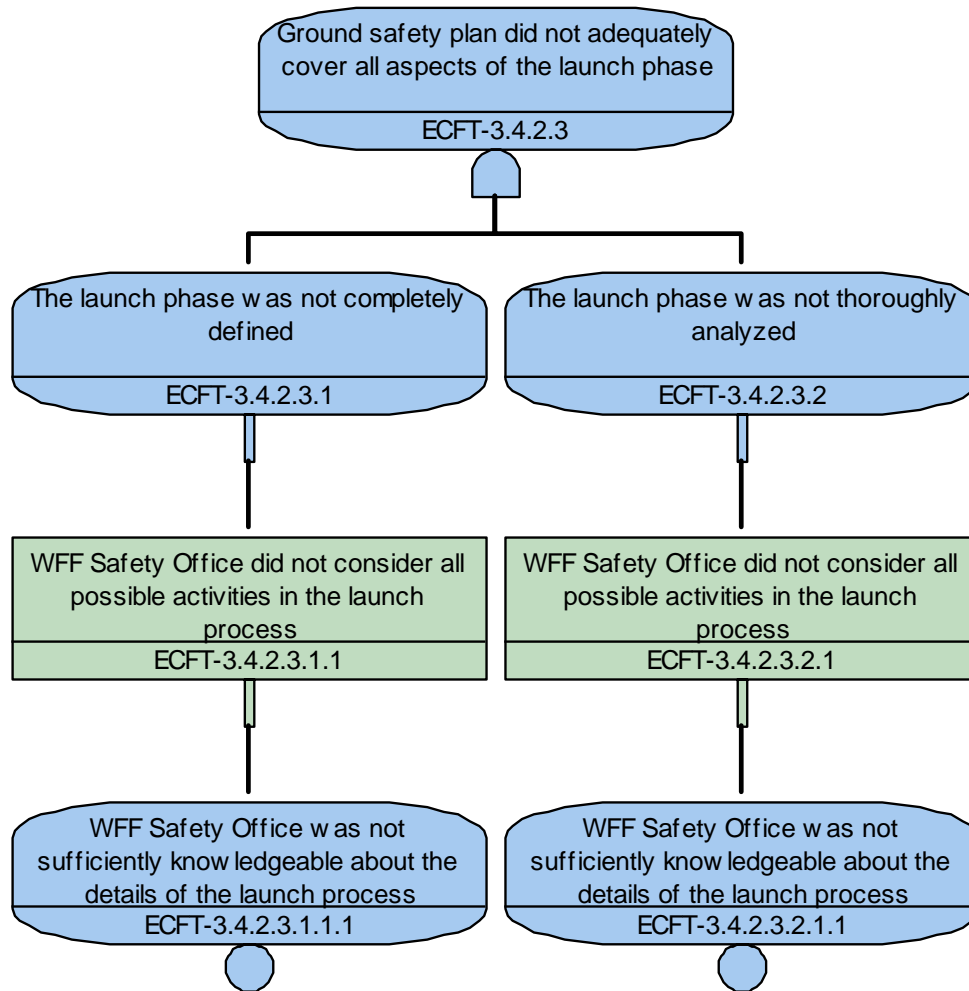
**Figure 79. The Ground Safety Plan Did Not Encompass All Hazards on the Ground**

- A. WFF Safety Office did not perform a complete hazard assessment. The WFF Safety Office is responsible, according to RSM 2002 Rev B, for developing the ground safety plan. This plan includes the only reference in the balloon safety documentation to hazards during ground operations. Only a subset of the actual hazards during ground operations is indicated and no full hazard analysis exists.
1. WFF safety leadership did not provide appropriate oversight to WFF Safety Office's responsibilities with regard to the balloon program. The safety leadership at WFF fully delegated responsibilities that had full bearing on safety of the public to the WFF Safety Office without any indication of audit or review of all aspects of safety. The remainder of the logic flow is as in several previously-described branches.



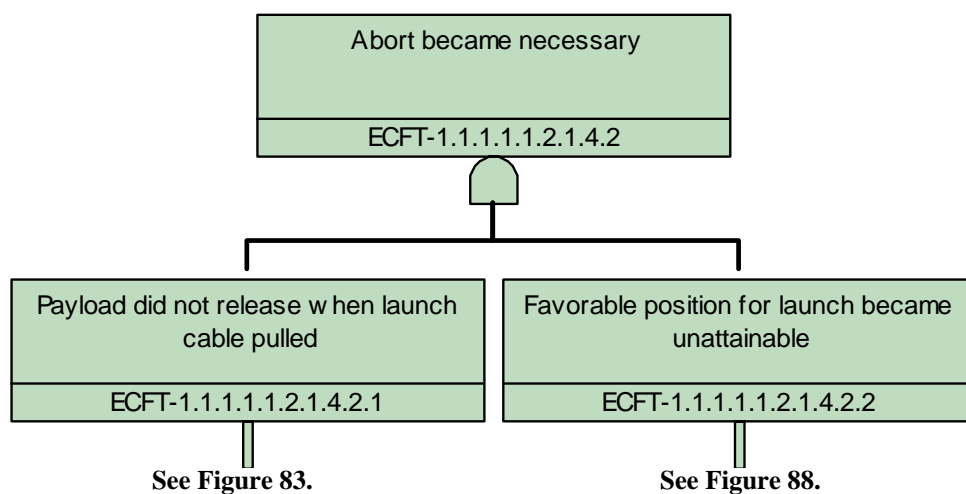
**Figure 80. The Ground Safety Plan Did Not Explicitly Address the General Public as a Target**

- A. WFF ground safety policy in RSM 2002 (Rev B) does not include protecting the general public. Dangers to the general public during ground operations were not understood or acknowledged.
  - 1. WFF safety leadership did not ensure complete flow down of NASA requirements to protect the public. RSM 2002 does not account for hazards to the general public during ground operations and protection of the public is not addressed in the CSBF documentation.



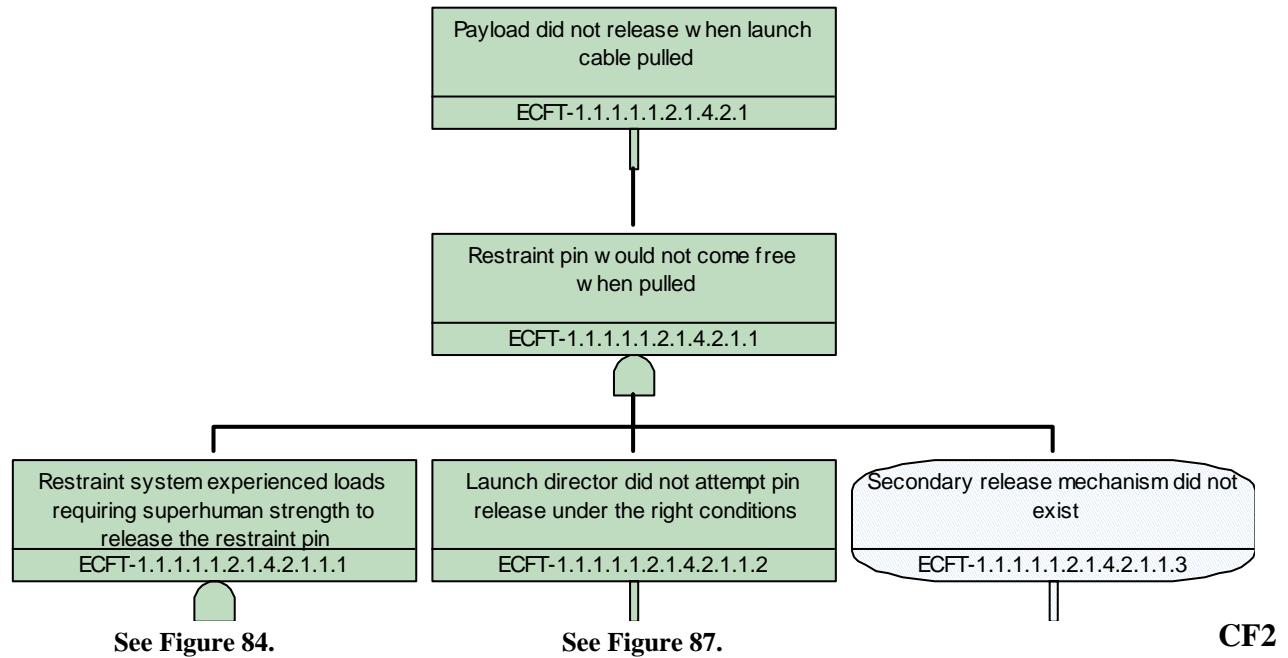
**Figure 81. The Ground Safety Plan Did Not Adequately Cover All Aspects of the Launch Phase**

- A. The launch phase was not completely defined. The process of moving the launch vehicle to chase the balloon, aligning the launch vehicle with the balloon, and attempting launch is not expressed in the Ground Safety Plan's description of the launch phase. This is indicated in documentation.
1. WFF Safety Office did not consider all possible activities in the launch process. There is very little about the launch process specified in the ground safety plan.
    - a. WFF Safety Office was not sufficiently knowledgeable about the details of the launch process. In particular, hazards to the public were not identified in the ground safety plan.
- B. The launch phase was not thoroughly analyzed. Key hazardous elements of launch operations were not addressed for the process of chasing the balloon to attempt launch. This was evident from review of the Ground Safety Plan. The remainder of the logic follows as in item A.



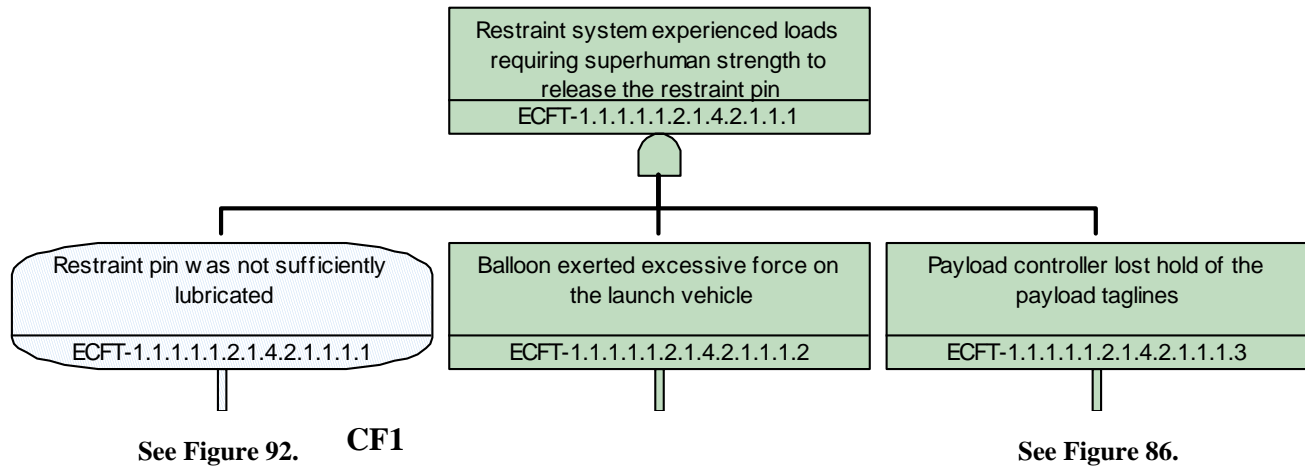
**Figure 82. Abort Became Necessary**

- A. Payload did not release when launch cable pulled. The pull force was insufficient to move the pin back from the pear ring and hence the payload remained attached to the launch vehicle. This was evident from video, test, and analysis.
  - B. Favorable position for launch became unattainable. With limited space based on the fence and the spectators, the balloon became too far offset from an appropriate position above the launch vehicle to ever be able to reach a position where launch would be feasible. This was evident from video and analysis.
-



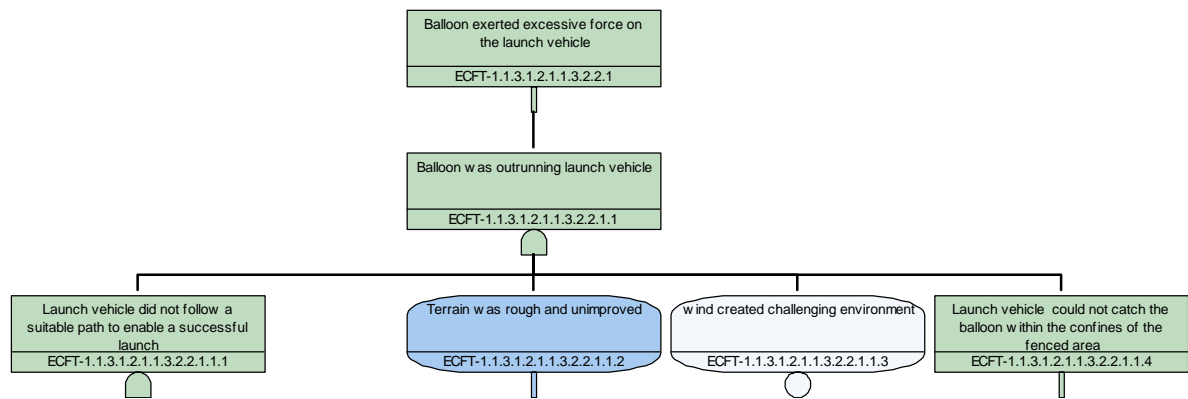
**Figure 83. Payload Did Not Release When Launch Cable Was Pulled**

- A. Restraint pin would not come free when pulled. The combined friction and spring force was higher than the force resolved at the pin from pulling the lanyard, according to video, analysis, and test.
1. Restraint system experienced loads requiring superhuman forces to enable release. Analysis shows that over 200 lb was required to free the pin in the configuration during the launch attempt. Normal human capability would be no greater than 100 lb pulling force.
  2. Launch director did not attempt pin release under the right conditions. The angle of the balloon relative to the vertical from above the launch vehicle was too great, causing a significant shear force on the pin, resulting in a significant friction force, preventing its release. This was indicated from analysis.
  3. A secondary release mechanism did not exist. Had there been a secondary mechanism that was not subject to the shear and friction force combination that limited the launch director's ability to release the pin, the payload may have released successfully. Analysis shows that the catenary angle, while large, would not likely have caused the payload to pendulum down and hit the ground upon launch. **Contributing Factor 2.** This leads to root cause R6 in the next block and is not shown again here.



**Figure 84. Release Mechanism Experienced Loads Requiring Superhuman Forces to Enable Release**

- A. Restraint pin was not sufficiently lubricated. While there is no evidence of requirements to lubricate the pin, without lubricant, the amount of friction force due to shear force imparted by horizontal motion or pull of the balloon can be arbitrary, and require a tremendous force to overcome. This was evident from analysis. **Contributing Factor 1.**
- B. Balloon exerted excessive force on the launch vehicle. The balloon being significantly ahead of the vehicle caused a large horizontal force on the launch vehicle. This was evident from video and analysis. The logic continues the flow in the middle branch of Figure 54.
- C. Payload controller (aka the payload launch assistant) lost hold of the taglines. When the straps used to stabilize the payload during launch were lost, it created a dynamic load on the launch mechanism adding to the force on the pin that the launch director would have to overcome for successful launch. This was evident from video and analysis.



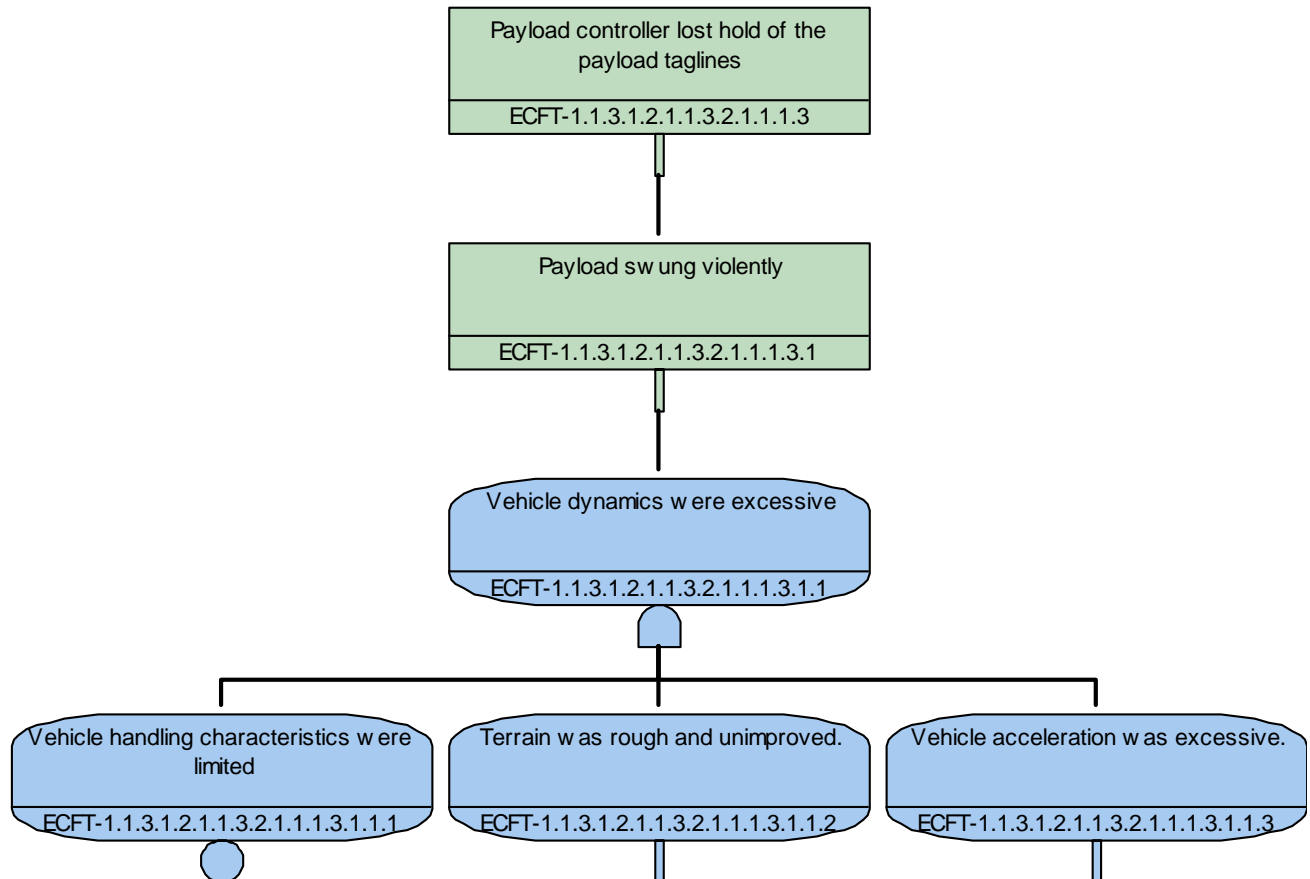
See Figure 89.

**I8**

**Figure 85. Balloon Exerted Excessive Force on the Launch Vehicle**

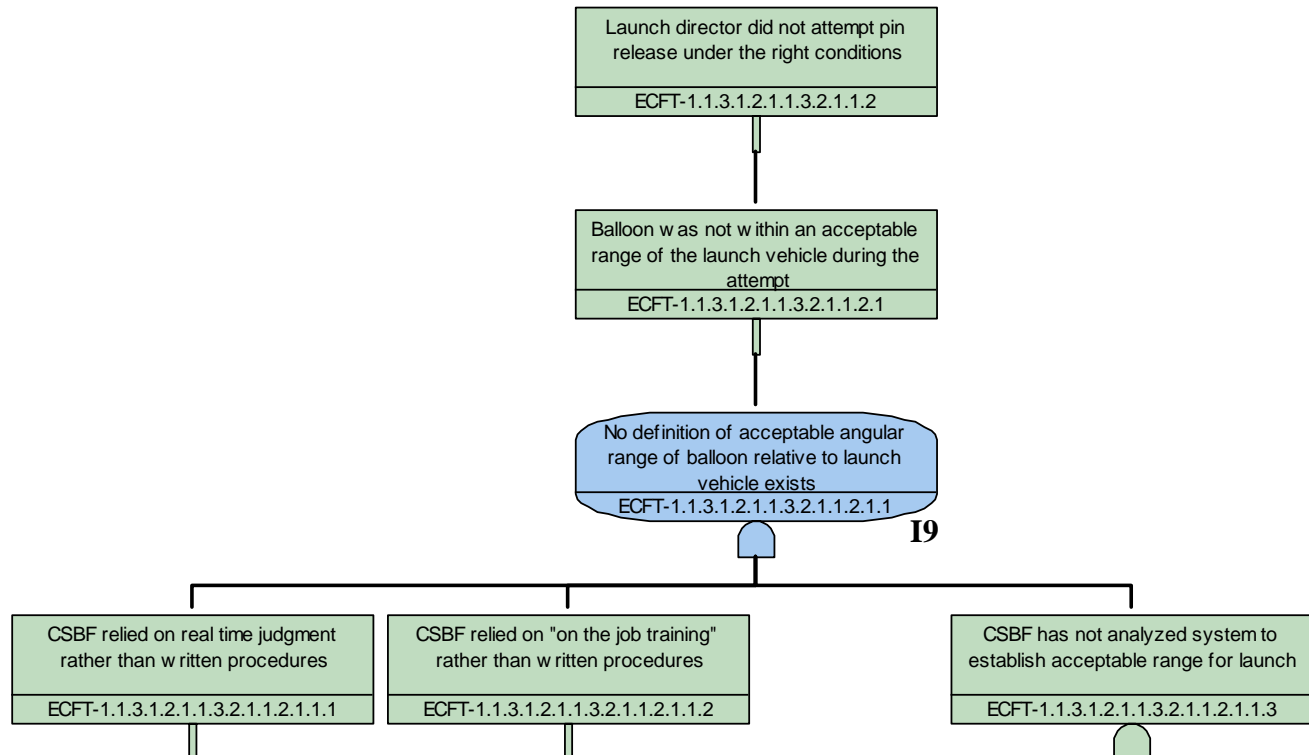
- A. The balloon was outrunning the launch vehicle. The balloon was ahead and getting further ahead and more and more challenging to catch.
1. Launch vehicle did not follow a suitable path to enable a successful launch. Some of the turns taken by the launch vehicle caused the vehicle to lose ground on catching the balloon. This is evident from interviews and video.
  2. Terrain was rough and unimproved. Logic in Figure 63 follows and is not repeated here.
- Intermediate Cause I8.**
3. The launch vehicle could not catch the balloon within the confines of the fenced area. The combination of speed limitations of the crane and the limited travel range of the vehicle due to the layout of the flight train and limited area prevented the launch vehicle from being able to catch the balloon (block not shown). This is evident from videos and documentation.





**Figure 86. Payload Controller Lost Hold of the Taglines**

- A. The payload swung violently, as observed in video evidence. This caused additional stresses on the hardware and made it more difficult to successfully release the payload from the vehicle.
1. Vehicle dynamics were excessive. Motions of the vehicle were imparting into the payload, as apparent from video evidence.
    - a. Vehicle handling characteristics were limited. There was, expectedly, a finite amount of speed, shock absorption, and lateral control capability.
    - b. Terrain was rough and unimproved. (See Figure 63.)
    - c. Vehicle acceleration was excessive. Specifically the deceleration due to a sudden stop caused a jolt, as evident from the video. The sudden stop was in order to make a launch attempt (block not shown).



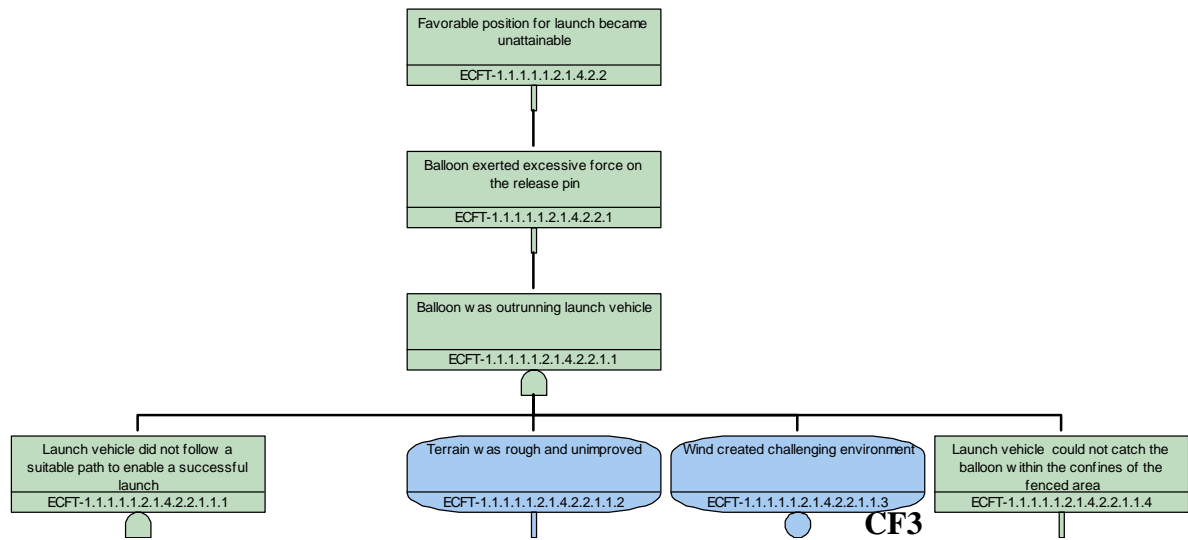
**Figure 87. Launch Director Did Not Attempt Release Under the Right Conditions**

A. Balloon was not within an acceptable range of the launch vehicle during the attempt. Analysis and test showed that the large angle with the vertical caused a significant shear force and hence friction force, which ultimately prevented the pin from releasing.

1. No definition of acceptable angular range of balloon relative to launch vehicle exists.

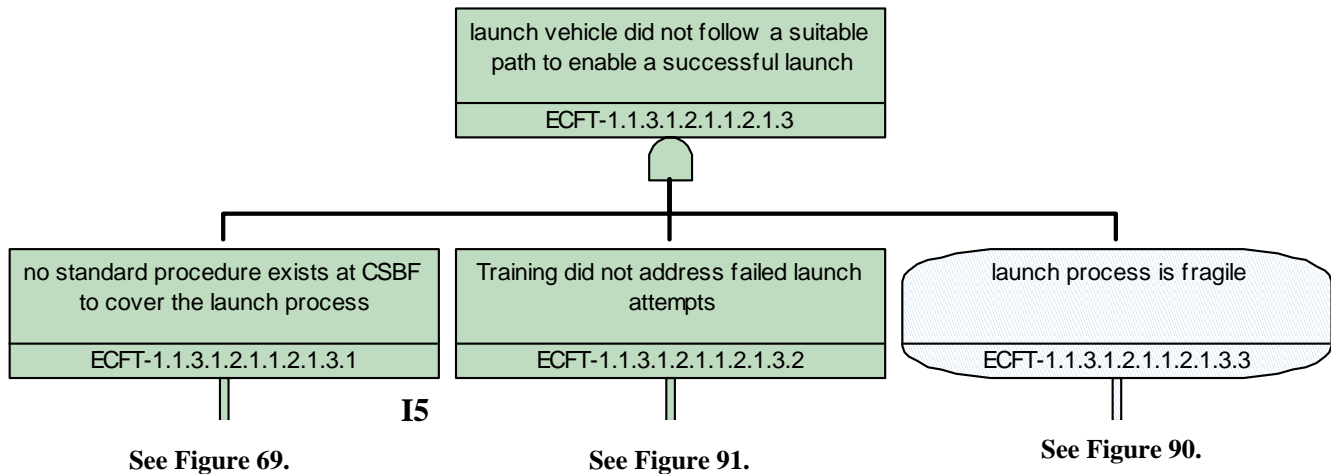
**Intermediate Cause I9**

- a. CSBF relied on real-time judgment rather than written procedures. The general approach has been to train the launch crew in a general sense and have them respond to the events with good judgment. This is evident from documentation and interview. The rest of this branch follows with the logic in Figure 60.
- b. CSBF relied on “on-the-job training” rather than written procedures. On-the-job training is used in place of explicit rules and procedures. This is evident from documentation and interview. The rest of this branch follows with the logic in Figure 60.
- c. CSBF has not analyzed the system to establish the acceptable range for launch. There is no evidence that anything but training and visual determination is used to decide when launch can take place. The rest of this branch leads to the same cause as determined from Figure 60.



**Figure 88. A Favorable Position for Launch Became Unattainable**

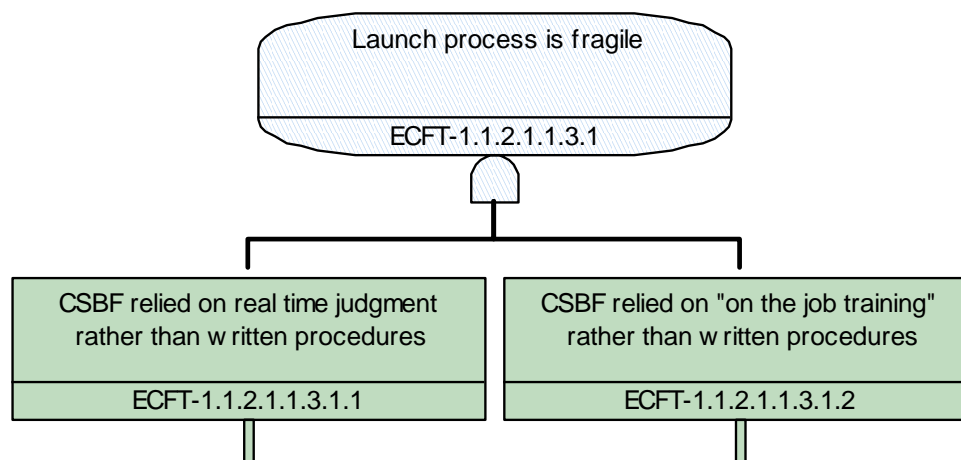
- A. Balloon exerted excessive force on the launch vehicle. This branch follows essentially the same logic path as that in Figure 84, with the addition of the “wind created challenging environment” block. Although the wind was not greater than allowable specifications, according to interview, it was strong enough to make the process of catching the balloon more challenging (**Contributing Factor 3**).



**Figure 89. Launch Vehicle Did Not Follow a Suitable Path to Enable a Successful Launch**

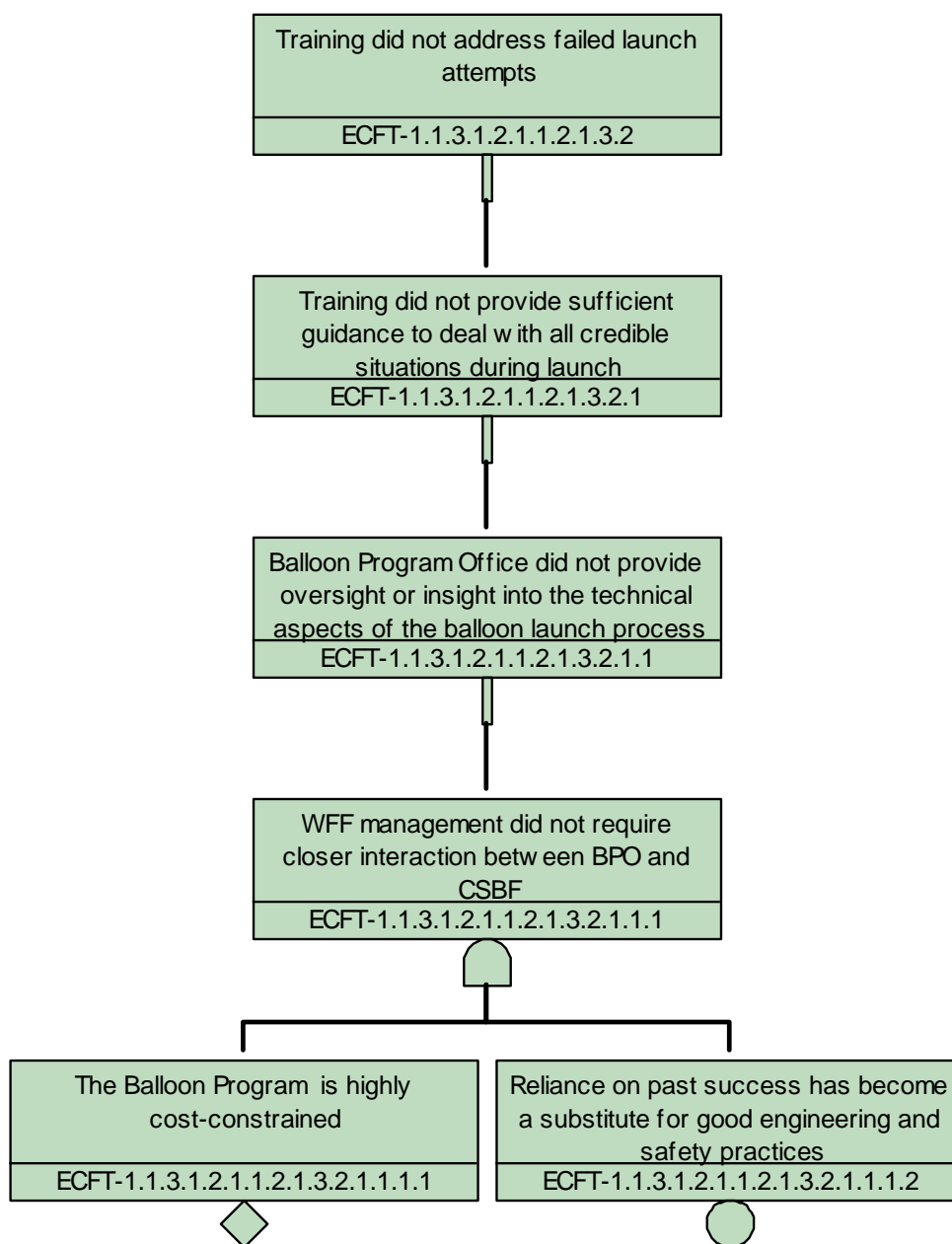
- A. No standard procedure exists at CSBF to cover the launch process. Given that the launch process is a hazardous operation, the contract with CSBF requires written procedures. This is evident from interview and documentation. **Intermediate Cause I5**

- B. Training did not address failed launch attempts. In particular, there is insufficient guidance for dealing with any anomalous or contingency situations. This is evident from interview and documentation. **Intermediate Cause I6**
- C. The launch process is fragile. Without explicit procedures and due to the dependency on visual assessment and good judgment, the launch process is highly sensitive to errors in judgment, perception, and visualization. This is evident from interview and documentation. **Contributing Factor 4**



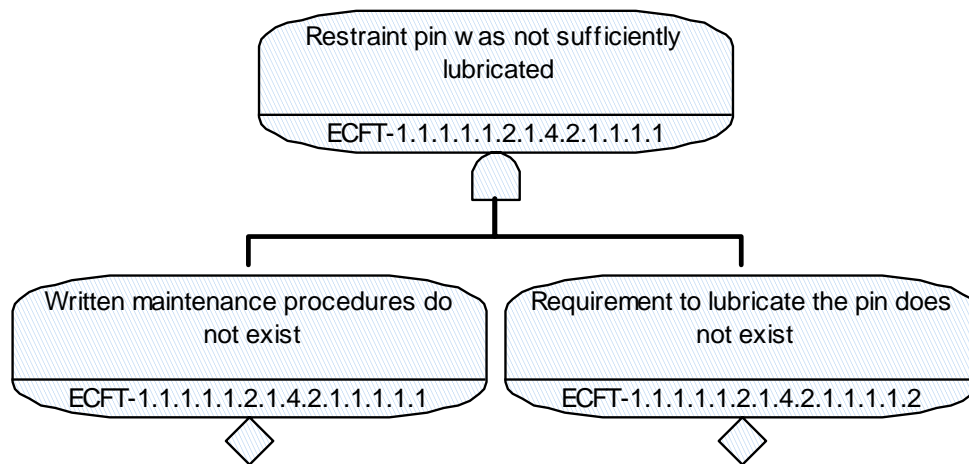
**Figure 90. The Launch Process Is Fragile**

- A. CSBF relied on real-time judgment rather than written procedures. Interview and documentation review indicate that the process of launching the balloon is not something that is written down, but rather is something of an art based on the observation of the surroundings and some general, unwritten guidelines. This block next leads to Root Cause R6: Reliance on past success has become a substitute for good engineering and safety practices.
- B. CSBF relied on “on-the-job training” rather than written procedures. Interview and documentation review indicate that on-the-job training is the means for conveying the process of launching the balloon, rather than writing down a procedure. This block next leads to Root Cause R6 as well.



**Figure 91. Training Did Not Address Failed Launch Attempts**

- A. Training did not provide sufficient guidance to deal with all credible situations during launch. Interviews indicated that there is no specific training element to deal with anomalies or unexpected occurrences. The rest of the branch follows Figure 60.



**Figure 92. Restraint Pin Was Not Sufficiently Lubricated**

- A. Written maintenance procedures do not exist. No evidence of maintenance was provided upon request to the MIB.
- B. A requirement to lubricate the pin does not exist. There was no information provided nor that provided from interviews to indicate lubrication requirements.

### 3.6.4 Secondary Undesired Outcome

In response to the direct language of the appointment letter, the MIB considered the real threat to lives of the public and their associated property as the primary undesired outcome of the mishap. During the course of the investigation, the MIB identified two additional undesired outcomes. This section addresses these undesired outcomes. For both secondary undesired outcomes (SUOs) the MIB used the work completed for the PUO, rather than complete additional, independent exhaustive analysis on each SUO.

The first secondary undesired outcome (SUO1) for this mishap was the **significant loss of assets including the scientific payload, the airport fence, and the costs associated with the failed launch attempt.**

The second secondary undesired outcome (SUO2) for the mishap was that **contractor personnel were endangered when the payload inadvertently released from the launch head.**

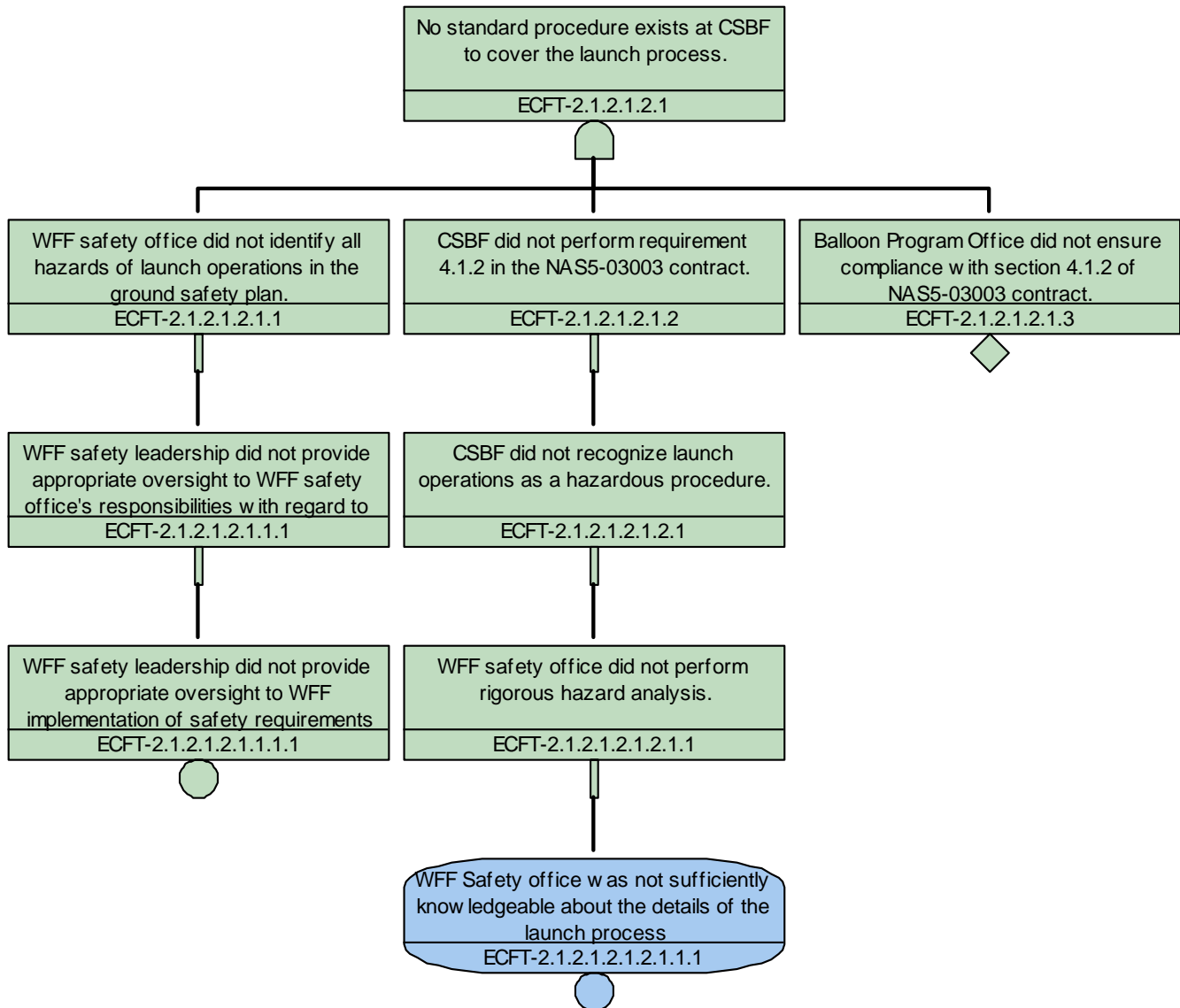
#### 3.6.4.1 ECF Analysis for SUO1 NASA incurred significant loss of assets including the scientific payload, the airport fence, and the costs associated with the failed launch attempt.

The MIB used the work products created in the analysis of the causes for the PUO as a starting point for analysis of the SUO1. Of the three PUO proximate causes (P), which included P1) payload separated from the launch vehicle, P2) released payload was dragged downwind by the balloon and P3) people in the general public were in the projected flight path, only causes P1 and P2 are necessary and sufficient to cause the asset loss that occurred during this mishap. These two proximate causes were then traced down the Event and Causal Factor Tree (E&CFT) to determine if the intermediate causes

for the PUO were necessary and sufficient for the SUO1.

Analysis of the E&CFT reveals that all causes and conditions are identical for SUO1 except for the following:

Cause: E&CFT-2.1.2.1.2.1 No Standard procedure exists at CSBF to cover the launch process. This branch of the E&CFT for the PUO is reproduced in Figure 93.



**Figure 93. Repeated From PUO—No Standard Procedure Exists at CSBF to Cover the Launch Process**

#### Discussion:

This cause traces down to three causes including 1) WFF Safety Office not identifying all hazards, 2) CSBF not establishing written procedures for hazardous operations and the 3)BPO not ensuring compliance with the NAS-03003 contract (which requires written procedures for hazardous operations).

The focus of these three intermediate causes for the PUO is to address the hazards and hazardous operations that target humans, specifically the public. For SUO1, the interpretation of these three intermediate cause and all causes that flow down from them must be expanded to include the assets as targets for the hazards. Likewise, causes associated with safety oversight must include safety of the assets.



That branch would be modified in the following manner to address the SUO1. The modified portions are discussed below.

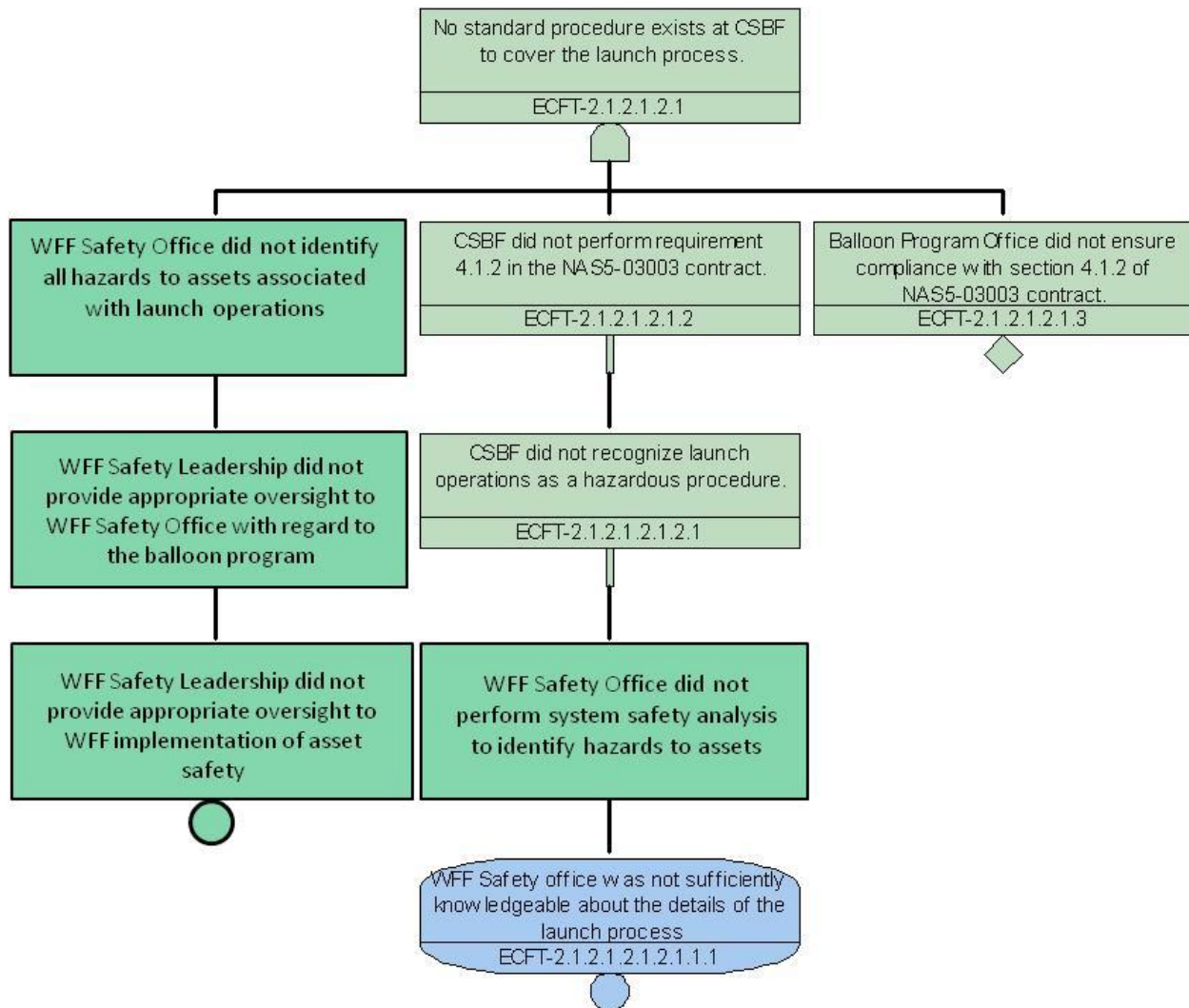


Figure 94. SUO1 - No Standard Procedure Exists at CSBF to Cover the Launch Process

It is evident from the documentation review that the value of the science payload was considered as part of the mission planning (820-CMPP-1002 "NCT Mission Project Plan"). However, the protection for this significant asset (as well as for assets such as the balloon, helium, and other facility assets) is not well addressed in any process documentation.

- A. **WFF Safety Leadership did not provide appropriate oversight to WFF SMA with regard to the balloon program.** There is no evidence that the leadership of the WFF Safety Office or Facility management required the consideration of hazards to assets in documentation, including procedures.

**1. WFF Safety Leadership did not provide appropriate oversight to WFF asset safety.  
Root Cause SR1**

**Recommendation:** WFF safety leadership should review and become knowledgeable about all safety requirements and plans implemented for the balloon program and ensure the proper flow-down of all safety requirements, including but not limited to NPR 8715.3 and NPR 8715.5 in order to protect the public, NASA workforce, high-value equipment and property and the environment.

This recommendation is identical to Recommendation A-3.

**B. WFF SMA did not perform systems safety analysis to identify hazards to assets.**

**Intermediate Cause SI1** Through the interview process, it was communicated that in general the launch operation is a hazardous operation for both humans and assets. This is also evident from the review of launch videos, including the NCT mishap data. The board found no documentation to show that the hazards to the assets were identified or analyzed as part of the system safety process for this mission.

**Recommendation:** WFF Safety Office should perform a complete hazard analysis, in accordance with NPR 8715.5, section 3.2 Range Safety Analysis. All phases of the balloon launch process should be considered. This hazard analysis should be validated by independent review.

This recommendation is identical to Recommendation II-1. Note that the proper execution of NPR 8715.3 and 8715.5 will encompass the analysis of hazards to the assets and the development of procedures required for mitigation.

**3.6.4.2 ECF Analysis for SUO2—Contractor personnel were endangered when the payload inadvertently released from the launch head.**

The MIB used the work products created in the analysis of the causes for the PUO as a starting point for analysis of the SUO2. Of the three PUO proximate causes (P), which included P1) payload separated from the launch vehicle, P2) released payload was dragged downwind by the balloon and P3) people in the general public were in the projected flight path, all causes are necessary and sufficient to cause the danger to the personnel that occurred during this mishap. These three proximate causes were then traced down the E&CFT to determine if the intermediate causes for the PUO were necessary and sufficient for the SUO2.

Analysis of the E&CFT reveals that all causes and conditions for POU are identical for SUO2.

The MIB feels that the recommendations produced from the PUO address the personnel safety issues for this secondary undesired outcome. No additional recommendations are required.

**3.6.5 Items Ruled Out**

The “Items Ruled Out” were initially considered during the construction of the mishap FT as either potential causes or potential contributing factors to the balloon launch mishap. Refuting evidence or the lack of substantiating evidence gathered during the investigation has subsequently allowed these

items to be ruled out as either causes or contributors. The following items were eliminated from further consideration and do not appear on the Event and Causal Factor Tree (E&CFT). They are listed in this section for the sake of completeness.

### 3.6.5.1 Potential Causes—Ruled Out

**PCRO-1: Eye bolt was faulty.** A visual inspection of the eyebolt and a favorable comparison of the manufacturer's ultimate load rating (7015 lbs) with the predicted load at time of failure provided evidence to rule out a faulty eyebolt as a potential cause.

**PCRO-2: CSBF launch team ignored the requirement that the Category A zone is valid from inflation through payload release.** Interview evidence substantiated that the launch team did consider the Category A zone valid throughout payload release. The zone was not closely monitored and breaching of the zone yielded no consequence; however evidence suggests that the zone was neither fully understood, clearly marked, nor closely monitored and that no procedures were in place to prescribe actions for breaching the zone. These factors were causes and contributors to the incident. There is a lack of evidence to suggest that the requirement was intentionally ignored; therefore this was ruled out as a potential cause

**PCRO-3: Launch mechanism broke.** Field Test 1 determined that the mechanism functioned nominally under no-load and showed that there were no mechanical or configuration-dependent conditions that prevented proper operation of the release mechanism; therefore, the launch mechanism broke was ruled out as a potential cause.

**PCRO-4: Cables were tangled, jamming release.** Visual inspection, a series of field tests and substantial photographic evidence provided the refuting evidence to rule out tangled cables jamming the release as a potential cause.

**PCRO-5: Launch mechanism was not properly assembled and/or maintained.** Visual inspection, a series of field tests, maintenance record review and photographic evidence provided the refuting evidence to rule out improper assembly and improper maintenance of the launch mechanism as potential causes. Note that the insufficient lubrication of the restraint pin was carried forward as a contributing factor. (Reference CF1)

**PCRO-6: Eyebolt was destroyed due to sabotage.** There is no evidence to support or even to raise suspicion that sabotage played a role in the incident; therefore eyebolt destroyed by sabotage was ruled out as a potential cause.

**PCRO-7: Eyebolt was destroyed due to horseplay.** There is no evidence to support or even to raise suspicion that horseplay played a role in the incident; therefore eyebolt destroyed by horseplay was ruled out as a potential cause.

**PCRO-8: Cables were frayed.** Visual inspection and photographic evidence ruled out that the cables were frayed; therefore frayed cables were ruled out as a potential cause.

**PCRO-9: Cables were destroyed due to sabotage.** There is no evidence to support or even to raise

suspicion that sabotage played a role in the incident; therefore cables destroyed by sabotage was ruled out as a potential cause.

**PCRO-10: Cables were destroyed due to horseplay.** There is no evidence to support or even to raise suspicion that horseplay played a role in the incident; therefore cables destroyed by horseplay was ruled out as a potential cause.

#### **3.6.5.2 Potential Contributing Factor—Ruled Out**

**PCFRO-1: Wind exceeded safe limits.** Refuting evidence provided by the Balloon Program Office showed that the winds at the time of launch were in family with historical wind conditions for previous NASA balloon launches. Winds exceeded safe limits was ruled out as a potential cause.

**PCFRO-2: Crane was in high-traction mode.** Evidence provided by interview was refuting evidence that the crane was in high-traction mode; therefore crane in high-traction mode was ruled out as a potential cause.

### **4.0 Findings**

This MIB found the following issues that contributed to this incident. Major causes, proximate and intermediate causes are discussed in this section.

#### **4.1 Proximate Causes**

A Proximate Cause is the event(s) that occurred, including any condition(s) that existed immediately before the undesired outcome, directly resulted in the occurrence of the undesired outcome and, if eliminated or modified, would have prevented the undesired outcome.

Based on this definition the MIB noted three (3) proximate causes for this mishap.

- P1 Proximate Cause: The NCT payload separated from the launch vehicle.**
- P2 Proximate Cause: The released payload was dragged downwind by the balloon.**
- P3 Proximate Cause: People in the general public were in the projected flight path.**

#### **4.2 Intermediate Causes**

An Intermediate Cause is an event or condition that created the proximate cause that, if eliminated or modified, would have prevented the proximate cause from occurring.

Based on this definition the MIB noted 14 significant intermediate causes. The following were the significant intermediate causes:

- I1 Intermediate Cause: WFF Safety Office did not perform rigorous hazard analysis.**
- I2 Intermediate Cause: A barrier to keep the general public out of all dangerous areas throughout the launch process did not exist.**
- I3 Intermediate Cause: No trained individual was in place to ensure public safety.**
- I4 Intermediate Cause: The ground safety plan did not cover all relevant hazards and**

**phases.**

- I5 Intermediate Cause: No complete and thorough standard procedure exists at CSBF to cover the launch process.**
- I6 Intermediate Cause: Launch crew training did not address failed launch attempts.**
- I7 Intermediate Cause: Category A hazard area during launch phase was not well-defined.**
- I8 Intermediate Cause: Terrain was rough and unimproved.**
- I9 Intermediate Cause: CSBF has not analyzed the payload release system to establish acceptable angular range of balloon relative to launch vehicle for launch attempt.**
- I10 Intermediate Cause: CSBF was not aware of hardware limitations that might give rise to a failure during a launch vehicle maneuver.**
- I11 Intermediate Cause: The ground safety plan did not explicitly address the protection of the general public.**
- I12 Intermediate Cause: The BPO did not have sufficient insight or oversight into the technical aspects of CSBF's balloon launch process.**
- I13 Intermediate Cause: WFF safety leadership did not provide appropriate oversight to WFF Safety Office's responsibilities with regard to the balloon program.**
- I14 Intermediate Cause: WFF safety leadership did not thoroughly review balloon safety documentation.**

### **4.3 Contributing Factors**

A Contributing Factor is an event or condition that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence.

Based on this definition the MIB noted the following contributing factors:

- CF1 Contributing Factor: Restraint pin was not sufficiently lubricated.**
- CF2 Contributing Factor: Secondary release mechanism did not exist.**
- CF3 Contributing Factor: Wind created a challenging environment.**
- CF4 Contributing Factor: The launch process is fragile.**

### **4.4 Root Causes**

A Root Cause is one of multiple factors (events, conditions, that are organizational factors) that contributed to or created the proximate cause and subsequent undesired outcome and, if eliminated or modified, would have prevented the undesired outcome.

Based on this definition, the MIB identified six (6) NASA Root Causes for this mishap.

- R1 Root Cause: WFF safety leadership did not ensure complete flow down of agency requirements to protect the public.**
- R2 Root Cause: WFF safety leadership did not provide appropriate oversight to WFF**

**implementation of safety requirements (WFF Safety Office and BPO as implementing organizations).**

- R3 Root Cause: WFF Safety Office was not sufficiently knowledgeable about the details of the balloon launch process.**
- R4 Root Cause: GSFC safety leadership did not verify or provide corrective action for flow-down of NASA requirements to protect the public.**
- R5 Root Cause: NASA Agency Range Safety Program failed to ensure corrective actions were accomplished from previous agency audits.**
- R6 Root Cause: Reliance on past success has become a substitute for good engineering and safety practices in the balloon program.**

#### **4.5 Observations**

Several Observations were noted during this investigation. Although these observations were not direct contributors to the mishap, the board determined that they would be beneficial in improving awareness and/or preventing other potential types of safety issues.

- O1 Observation: The hanging heavy payload was not identified as a hazard.**
- O2 Observation: The Launch Director was not wearing protective equipment for his hands while pulling the launch lanyard.**
- O3 Observation: The audits conducted of WFF safety in 2002 resulted in recommendations that, if properly implemented, would have made the undesired outcome extremely unlikely.**
- O4 Observation: Leaving the BPO and the CSBF responsible for classifying mishaps gives rise to sidestepping the requirements of a NASA incident response team.**
- O5 Observation: The Balloon Ground Safety Plan (BGSP) identifies an institutional RSQA, but it's not clear whether this is a person, organization, or a virtual entity.**
- O6 Observation: During the course of the investigation, the MIB obtained copies of two operating permits that were issued by Australia's Civil Aviation and Safety Authority (CASA): WOA 7058 dated 8 February 2010 and WOA 8064 dated 30 April 2010. The launch attempt of the NCT payload fell under the authority of WOA 7058. WOA 8064 was issued by CASA after the mishap. The "Approval" section of WOA 7058 states "I approve the area of Alice Springs Airport S23<sup>0</sup> 48.4; E133<sup>0</sup> 54.1 as an approved area for the operation of a heavy balloon." The MIB found the language to be ambiguous in that an area could not be defined by a single latitude/longitude point. The MIB observed that a revised permit (WOA 8064), accomplished after the mishap, contained a drawing that shows shaded "patrolled" area and one "closed" gate. Copies of these permits are shown in Appendix J. The MIB notes that both CASA operating permits contain ambiguous language regarding the approved area and that the shaded area in the revised permit is not adequate to cover all possible launch layout possibilities.**

- O7**      **Observation: Documented mishap response and recovery (contingency action plans) do not meet the requirements of NPR 8621.1B. There are no documented IRT processes in place. This was evident in all post mishap video and photos that depicted the general public within the vicinity of unexpended pyros, smoking chemical batteries, and dangerously sharp pieces of wreckage. Additionally, the CSBF team was observed with the science team handling the wreckage without any PPE. Interviews indicated that the personnel had no idea of what the recovery requirements were (if any). This lack of post mishap recovery requirements also led to the discard of damaged payload material to a scrap yard for recycling and the shipment of other payload material back to a university in California instead of being impounded. This was all done without the approval of the Investigating Authority (MIB). This was in violation of the NPR 8621.1.B requirements.**
- O8**      **Observation: BPO Mishap investigation and reporting is being conducted under 820-PG-8621.1.1B. The requirements in 820-PG-8621.1.1B do not meet the Agency's requirements documented in NPR 8621.1B.**
- O9**      **Observation: The safety organization at GSFC's WFF is not independent from projects and lacks the direct SMA reporting path that exists at GSFC's Greenbelt facility.**
- O10**     **Observation: CSBF personnel seemed unaware of a number of operational hazards and constraints.**
- O11**     **Observation: Members of the CSBF launch crew were not wearing hard hats during the launch operation as required by Section 4.1 of the Ground Safety Data Package.**
- O12**     **Observation: The Corrective Action from a previous balloon close call was not implemented for this program despite their apparent applicability. The Corrective Action was to require additional PPE and a protective structure for the launch crew. The incident (reference IRIS 2000-231-00012) involved a payload swinging out of control and nearly hitting crew members on the launch platform.**

## 5.0 Recommendations

This section is a compilation of the recommendations that were derived from the findings identified by this investigation. Each one has been identified by the number used in the report and is traceable to the exact finding that it represents.

**Table 4—Recommendations**

<b>Recommendation</b>		<b>Root Cause, Intermediate Cause, Contributing Factor, Observation</b>
<b>A-1</b>	WFF safety leadership should verify that all elements of the public (people in nearby populated areas, spectators, and passers-by) as well as NASA workforce, high-value equipment and property and the environment are protected from all credible hazards, identified by thorough, formal, hazard analysis, covering all phases of balloon operations from set-up through termination and recovery.	<b>R1, R2</b>
<b>A-2</b>	WFF safety leadership should regularly verify, through a minimum annual audit, BPO's oversight of safety at balloon launches and the WFF Safety Office's activities to ensure safety at balloon launches.	<b>R2</b>
<b>A-3</b>	WFF safety leadership should review and become knowledgeable about all safety requirements and plans implemented for the balloon program and ensure the proper flow-down of safety requirements, including but not limited to NPR 8715.3 and NPR 8715.5 in order to protect the public, NASA workforce, high-value equipment, property and the environment.	<b>R1, R2</b>
<b>B-1</b>	WFF Safety Office should obtain expertise in the precise details of the balloon launch process through training and direct interaction to ensure their own capability to produce balloon ground safety documentation	<b>R3</b>
<b>C-1</b>	GSFC safety leadership should provide oversight to ensure that exhaustive measures are taken to safeguard the public in the balloon program with no less fervor than is imparted to other activities and programs at GSFC. The GSFC safety leadership should also provide oversight to ensure protection of the NASA workforce, high-value equipment, property, and the environment.	<b>R4</b>
<b>D-1</b>	NASA Agency Range Safety Program should exhaustively follow up on audit recommendations and elevate any conditions of inaction for safety-related concerns to prevent unsafe activities from continuing.	<b>R5</b>
<b>D-2</b>	NASA Range Safety audit functions should be added to the NASA Safety Center Audits and Assessments responsibilities.	<b>R5</b>
<b>E-1</b>	The BPO, WFF, GSFC, and SMD should avoid considering a particular mission success rate or lack of safety incidents to be a sign that activities have been or are currently safe.	<b>R6</b>
<b>E-2</b>	NASA Safety Center (NSC) should generate a Case Study based on the common problem that the reliance on past success becomes a substitute for good engineering and safety practices.	<b>R6</b>



<b>Recommendation</b>		<b>Root Cause, Intermediate Cause, Contributing Factor, Observation</b>
<b>SUO R1-1</b>	WFF safety leadership should review and become knowledgeable about all safety requirements and plans implemented for the balloon program and ensure the proper flow-down of all safety requirements, including but not limited to NPR 8715.3 and NPR 8715.5 in order to protect the public, NASA workforce, high-value equipment and property and the environment.  This recommendation is identical to Recommendation A-3.	<b>R1, R2</b>
<b>I1-1</b>	WFF Safety Office should perform a complete hazard analysis in accordance with the NPR 8715.5 section 3.2 Range Safety Analysis. All phases of the balloon launch process should be considered. This hazard analysis should be validated by independent review.	<b>I1</b>
<b>I2-1</b>	In each launch location, the BPO should ensure that dedicated safety personnel thoroughly examine(s) the potential for spectators or passers-by entering hazardous areas and implement barriers or controls to prevent entry during the launch process.	<b>I2</b>
<b>I3-1</b>	WFF Safety Office should assign a range safety officer who is properly trained in range safety and who does not have a role in ensuring mission success.	<b>I3</b>
<b>I4-1</b>	The WFF Safety Office should revise the BGSP to cover all phases, from inflation through recovery, identify all hazards from the Hazard Analysis, and resulting restrictions and implementation of operational requirements.	<b>I4</b>
<b>I5-1</b>	The BPO should develop a hazardous operating procedure to cover the launch process in accordance with NPR 8715.3, Section 3.8 Hazardous Operations.	<b>I5</b>
<b>I5-2</b>	BPO should establish Launch Commit Criteria and flight rules.	<b>I5</b>
<b>I5-3</b>	BPO should establish and document firm and unambiguous criteria for aborts during the launch phase.	<b>I5</b>
<b>I6-1</b>	BPO should ensure that training for the launch crew covers the widest possible set of anomalous occurrences in the launch process including, but not limited to, failed launch attempts, breaches and near-breaches of the Hazard Zone, loss of payload control straps, loss of communication, and scenarios that would lead to an abort.	<b>I6</b>
<b>I7-1</b>	WFF Safety Office should clearly and unambiguously define the Category A hazard area and should require that it be implementable in practice with visible markings.	<b>I7</b>
<b>I8-1</b>	BPO should perform a cost, utility, and feasibility assessment for improving the terrain at Alice Springs Airport.	<b>I8</b>
<b>I9-1</b>	BPO should require in the contract that CSBF perform a thorough analysis of the payload restraint and release system to establish an acceptable angular range of balloon relative to crane for launch attempt.	<b>I9</b>

<b>Recommendation</b>		<b>Root Cause, Intermediate Cause, Contributing Factor, Observation</b>
<b>I10-1</b>	BPO should evaluate balloon launch hardware mechanisms through testing and review of documentation and specifications to determine proper operating conditions and ranges. The results of this evaluation should then be used to define operating limits of launch hardware and specify abort criteria.	<b>I10</b>
<b>I11-1</b>	WFF Safety Office should specifically address how to deal with the general public in the ground safety plan.	<b>I11</b>
<b>I12-1</b>	The BPO should become knowledgeable about the technical aspects of the launch process and gain an understanding of the hardware capabilities, limitations, operating bounds, and failure modes.	<b>I12</b>
<b>I13-1</b>	WFF safety leadership should ensure that WFF Safety Office is implementing an effective safety program that is applicable and consistent across the facility and for all contracts.	<b>I13</b>
<b>I14-1</b>	WFF safety leadership should review WFF balloon safety documentation for clarity and accuracy through a formal review process on at least an annual basis.	<b>I14</b>
<b>CF1-1</b>	BPO should perform analysis and/or test to determine the relationship between pin lubrication and lanyard pull force to establish lubrication guidelines for proper operation.	<b>CF1</b>
<b>CF2-1</b>	BPO should analyze, evaluate, and test the hardware to understand its capabilities and operating range, as well as to determine failures and associated sensitivities.	<b>CF2</b>
<b>CF3-1</b>	The BPO should establish firm, written criteria for wind limits and factor these into all go/no-go and abort criteria and any specific restrictions on a particular launch.	<b>CF3</b>
<b>CF4-1</b>	A. The BPO should develop a hazardous operating procedure to cover the launch process in accordance with NPR 8715.3, Section 3.8 Hazardous Operations.  B. BPO should ensure that training for the launch crew covers the widest possible set of anomalous occurrences in the launch process including, but not limited to, failed launch attempts, breaches and near-breaches of the Hazard Zone, loss of payload control straps, loss of communication, and scenarios that would lead to an abort.	<b>CF4</b>
<b>O1-1</b>	WFF Safety Office should identify the hanging payload as a hazard and follow relevant standards and requirements for hanging payloads to ensure protection of personnel and the general public.	<b>O1</b>
<b>O2-1</b>	WFF Safety Office should determine whether gloves or other PPE should be required for pulling the launch lanyard.	<b>O2</b>
<b>O3-1</b>	WFF Safety Office should ensure that all actions from the 2002 independent	<b>O3</b>

<b>Recommendation</b>		<b>Root Cause, Intermediate Cause, Contributing Factor, Observation</b>
	assessment are closed out thoroughly and completely, in particular, Items 5, 6, 9, and 21 referenced from the document "WFF range safety independent assessment response." GSFC safety management and the NSC should verify compliance with these recommendations.	
<b>O4-1</b>	WFF safety leadership should ensure that the mishap and contingency plan along with contracts associated with balloon campaigns adhere to requirements for an Incident Response Team (IRT) put forth in NPR 8621.1B.	<b>O4</b>
<b>O5-1</b>	The RSQA for CSBF should be an approving authority and knowledgeable about the BGSP and should be responsible for ensuring its completeness and proper implementation in the field.	<b>O5</b>
<b>O6-1</b>	The BPO should determine the full intention of CASA operating permits issued by the Australian government and be sure that they are properly implemented by CSBF and UNSW, along with stand-alone NASA range requirements.	<b>O6</b>
<b>O7-1</b>	WFF safety leadership should develop a mishap preparedness and contingency plan for BPO that adheres to the requirements put forth in NPR 8621.1B.	<b>O7</b>
<b>O8-1</b>	WFF needs to ensure that mishaps are appropriately classified and investigations are accomplished in accordance with NPR 8621.1B. Any program level procedures for mishap investigation and reporting should be coordinated with Code 300 and if necessary with OSMA to ensure they meet the agency level requirements.	<b>O8</b>
<b>O9-1</b>	GSFC should establish an organizational structure for safety that is consistent across Goddard's Greenbelt and Wallops facilities, where the entire chain of the safety organization below the GSFC Center Director is independent of the projects, as is currently in place for the Code 300 organization at Goddard's Greenbelt facility.	<b>O9</b>
<b>O12-1</b>	The BPO and the WFF Safety Office should ensure that all applicable lessons learned relating to balloon launches, including IRIS reports are examined and if applicable, that the corrective actions are implemented across the balloon program.	<b>O12</b>